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Estudio y conservación del lince ibérico *(Lynx pardinus)* en España

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PRESENTADA POR

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Tesis Doctoral

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Germán Garrote Alonso	Dr. José Luis Tellería Jorge

A mis padres y mi hermana

A Mario

"Es un gato grande con los ojos grandes
que al mover la cola transmite emoción
de largas patillas con sus zapatillas
da un salto muy grande y entra en acción

Siempre solitario por su itinerario
va muy silencioso nunca llama la atención
tiene mucha vista y es gran velocista
a pesar de todo está en peligro de extinción"

Kiko Veneno. El Lince Ramón.

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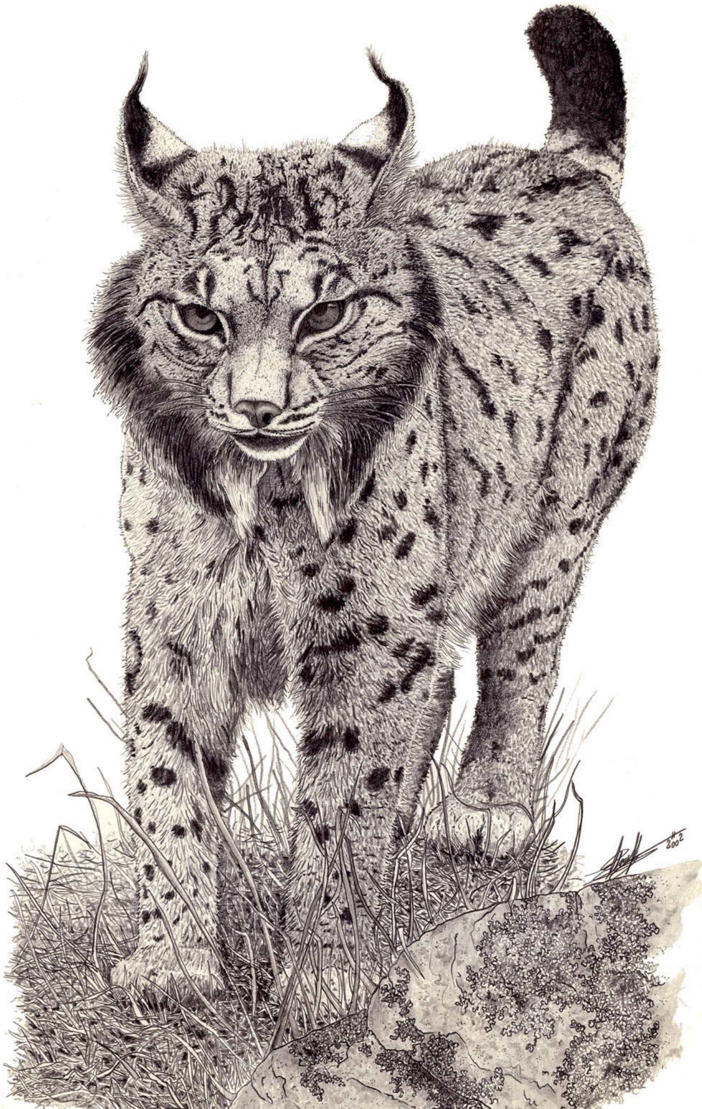

INTRODUCCIÓN GENERAL

El conocimiento de la distribución y abundancia de las especies, así como sus tasas de supervivencia y causas de mortalidad, juegan un papel importante a la hora de establecer sus requerimientos ecológicos, evaluar el estado de sus poblaciones y predecir la evolución de las mismas (Lomolino *et al*. 1995; Sanderson *et al*. 2002). De esta forma, el estudio de la evolución de las poblaciones de una especie permite identificar los factores clave que determinan sus tendencias (positiva o negativa), y la identificación de los factores negativos es fundamental en el caso de poblaciones en declive, ya que estos deben ser eliminados previamente a los esfuerzos de conservación y/o reintroducción (UICN 1998). Para ello, es primordial que la información utilizada sea fiable (Eberhardt 1985; Gaillard *et al*. 2003). Obtener esta información es, sin embargo, particularmente difícil en el caso de los felinos silvestres debido a que suelen ser escasos, sus poblaciones presentan bajas densidades, y tienen hábitos elusivos (Nowell y Jackson 1996). Este es el objetivo general de esta tesis, centrada en el estudio de los procedimientos de seguimiento de una especie amenazada y en el análisis de alguno de los aspectos que condicionan su supervivencia.

El lince Ibérico.

Presentación

El lince ibérico, *Lynx pardinus* (Temminck 1827), clasificado "En Peligro Crítico" (UICN 2001), está considerado el carnívoro más amenazado de Europa, (Mallinson 1978) y la especie más amenazada de la familia Felidae (Nowell y Jackson 1996). Endémico de la Península Ibérica (Rodríguez y Delibes 1992) y asociado al matorral mediterráneo (Palomares 2001), el Lince ibérico es un especialista trófico, estrictamente dependiente del conejo de monte (*Orictolagus cuniculus*; Delibes *et al*. 2000).

Aunque existen registros de linces ibéricos (la subespecie *Lynx pardinus spelaeus*, Boule 1910) en el sur de Francia durante el Pleistoceno tardío (Kurtén y Granqvist 1987), no hay ninguna evidencia de *Lynx pardinus* fuera de la Península Ibérica durante el último máximo glacial (Sommer y Benecke 2005). La presencia postglacial de *Lynx pardinus* en Francia no está del todo clara, aunque algunos restos de lince ibérico se han registrado en Francia desde el Holoceno hasta la Edad del Hierro (Vigne 1996; Vigne y Pascal 2003). Se cree que el lince ibérico ha sido endémico de la Península Ibérica durante la mayor parte del Cuaternario tardío, donde coexistió con su especie presa principal, el conejo de monte (Branco *et al*. 2002; López-Martínez 2008). También se ha sugerido que la colonización de Europa por el lince boreal, acaecida en Pleistoceno Superior, podría haber desplazado al lince ibérico de Centroeuropa hasta ubicarse de nuevo en la Península, donde la especie presentaría ventajas adaptativas (Kurtén y Granqvist 1987).

Evolución de sus poblaciones.

A finales del siglo XIX, Graells (1897) apuntó que "el gato clavo se encuentra en mayor o menor número en casi todas las regiones de nuestra península, y es más común hallarlo en las provincias meridionales y del centro que en las del norte y litoral". Ya en los primeros años del siglo XX Cabrera (1914) describió una distribución más restringida de la especie: "En el norte y este parece haberse extinguido, o por lo menos es muy raro, mientras que en el centro y mediodía todavía abunda". Tras casi medio siglo sin información, Valverde (1963) estableció la distribución del lince ibérico a escala nacional con datos de ejemplares abatidos desde los años 40. Estableció su presencia en poblaciones inconexas (figura 1) situadas en localidades de los Pirineos, Sierras del norte de Castellón, Sierra de Gata, Sierras del noroeste de Badajoz, Montes de Toledo, Sierra Morena y Doñana, añadiendo que "en algunas de ellas quizá no exista ya, y en las restantes es sumamente raro, con la honrosa excepción de unos pocos montes cuyos dueños les protegen". Ya a mediados del siglo XX el autor situó a la especie en el borde de la extinción, indicando que "su desaparición es inminente si no se toman medidas para evitarla". En los años 70, Garzón (1973) y Delibes (1979) realizan sendas aproximaciones a la distribución del lince, con resultados semejantes a los obtenidos por Valverde, donde el grueso de la población se centraba en el cuadrante suroccidental de la Península, con tendencia a presentar una distribución discontinua. Durante la década de los 80, Rodríguez y Delibes (1990, 2002) realizan una estimación retrospectiva de la distribución del lince ibérico desde la década de los 50 en base a datos de avistamientos de la especie obtenidos mediante encuestas, estimando un rango de distribución bastante más extenso del estimado por Valverde (1963), Garzón (1973) y Delibes (1979) para las mismas décadas (figura 1).

Figura 1. Distribución del lince ibérico en España a principios de los años 60 según Valverde (1963; izquierda) y Rodríguez y Delibes (1990;derecha).

En el mismo trabajo se calculó la distribución y abundancia del lince ibérico para la década de los 80 (Rodriguez y Delibes 1990, 1992), estimándose una población de 1.000-1.200 linces (unas 350 hembras reproductoras) distribuidos en 48 áreas de presencia estable, agrupadas en 9 poblaciones aisladas (Sierra Central occidental, Gredos, Alto Alberche, Sierra de San Pedro, Montes de Toledo-Villuercas-Monfragüe, Subbéticas, Sierra Morena oriental, Sierra Morena central, Sierra Morena occidental y Doñana) que ocupaban una superficie total de 11.000 km^2 (Figura 2). El 96% de las áreas detectadas entonces no alcanzaban un tamaño efectivo de la población de 50 (N_e minino), el límite teórico bajo el cual la variabilidad genética parece descender rápidamente (Franklin 1980). El pequeño tamaño de estas poblaciones hacía que todas excepto una (Población Central= Montes de Toledo y Sierra Morena Oriental) fueran posiblemente inviables a largo plazo debido a su vulnerabilidad frente a eventos estocásticos (Shaffer 1981). Para la misma década se estimó que en Portugal quedaban 45 linces, distribuidos en cuatro subpoblaciones (tres de ellas compartidas con España) que ocupaban un área de 2.400 km^2 (Castro y Palma 1996).

La pérdida del hábitat, la mortalidad no natural y la reducción de las poblaciones de conejo parecen haber sido las causas más importantes de la situación del lince ibérico en la década de los 80 (Garzón 1978; Delibes 1979; Rodríguez y Delibes 1992). Éstas provocaron la fragmentación de la distribución de la especie, originando problemas de viabilidad genética

Figura 2. Distribución del lince ibérico estimada para la década de los 80 en España y Portugal (Izquierda; Rodríguez y Delibes 1990; Castro y Palma 1996) y para principios del siglo XXI (derecha; Guzmán *et al*. 2004).

y un mayor riesgo de extinción de poblaciones de menor tamaño tanto por factores determinísticos como estocásticos (Rodríguez y Delibes 2004). Estos problemas han perdurado con el pasar de los años, pero la importancia relativa que cada uno de ellos ha tenido sobre la evolución de las poblaciones de lince ibérico ha variado a lo largo del tiempo y del espacio.

Causas de su regresión

Hasta la década de los cincuenta, se reconoce la caza intensiva como la primera causa de extinción del lince ibérico de grandes zonas de hábitat favorable (Rodríguez y Delibes 1992). Hasta la primera mitad del siglo XX, miles de linces fueron matados por su piel. Se estima que unas 500 pieles anuales se comercializaron en España hasta 1937 (Zofio y Vega 2000). En 1953, se crearon las *Juntas Rectoras de Extinción de Animales Dañinos y Protección de la Caza,* mediante las cuales la captura de cualquier especie de carnívoro, incluido el lince ibérico, era recompensada. La caza del lince fue prohibida en 1966 y Con el *Decreto de 5 de octubre de 1973*, se pone fin a estas entidades y se protegen determinadas especies salvajes, entre ellas el lince. Durante las dos décadas de existencia de estos grupos de extinción de carnívoros, las poblaciones de la mayoría de los predadores españoles fueron drásticamente reducidas (Cabezas Díaz *et al.* 2009), situando a muchas de las especies al borde de la extinción.

La pérdida de hábitat como consecuencia del cambio en los usos en los cambios del suelo, y principalmente la reducción de las poblaciones de conejo como consecuencia de la irrupción de la mixomatosis han sido argumentadas como principales causas de la desaparición de la especie en la segunda mitad del siglo XX (Garzón 1978; Delibes 1979; Rodríguez y Delibes 1992). A finales de la década de los ochenta, irrumpe la Enfermedad Hemorrágico Vírica (EHV) que atacó a las poblaciones de conejo a nivel mundial y castigó severamente a las poblaciones ibéricas (Villafuerte *et al*. 1994, 1995), previamente mermadas por los efectos de la mixomatosis, llegando a provocar unas tasas de mortalidad de hasta el 80% (Peiró y Selva 1991; Blanco y Villafuerte 1993; Villafuerte *et al*. 1995; Calvete *et al*. 2002). En los primeros años de la década de los 90, las poblaciones de conejo se habían reducido a la mitad respecto a los valores existentes antes de la llegada de la EHV (Blanco y Villafuerte 1993; Villafuerte *et al*. 1995). En la década de los 90 se realizaron estudios parciales sobre la situación del lince en la Península Ibérica, en los que se apunta un descenso de las poblaciones de la especie y la reducción e incluso desaparición de las poblaciones de conejos en buena parte del área de distribución del lince ibérico (Aldama 1996; Guzmán 1997; CBC 1997; ARENA 1999). Al igual que los trabajos de distribución previos (Rodríguez y Delibes 1992,1990; Castro y Palma 1996) la metodología utilizada se basó en el uso de avistamientos de linces recopilados a través de encuestas y entrevistas personales como indicadores de la presencia de la especie. El uso de este tipo de datos para establecer la distribución de las especies ha sido ampliamente criticado debido a que puede producirse la identificación errónea de la especie avistada (Huber y Kaczensky 1998; McKelvey *et al*. 2008; Lozier *et al*. 2009; Boshoff y Kerley 2010; Molinari Jobin *et al*. 2012). Una identificación errónea implica la aparición de falsos-positivos que pueden generar sobreestimas de la distribución de las especies (Molinari-Jobin *et al*. 2012), errores al establecer la magnitud en la que se produce la pérdida de su área de distribución (Aubry y Lewis 2000; Aubry *et al*. 2007) o asumir la presencia de la especie donde nunca estuvo (Sanderson 2009). Para el caso del lince ibérico, Gil y McCain (2011) reconstruyeron su distribución en España desde 1940 hasta principios del siglo XXI usando tan sólo datos históricos verificados con evidencias físicas indiscutibles (registros de pieles, huesos y cráneos de ejemplares conservados). Los autores sugieren que durante la segunda mitad del siglo XX, la presencia de la especie fue muy escasa fuera de Montes de Toledo, Sierra Morena y Doñana, ofreciendo el escenario de una distribución fragmentada similar a la estimada por

Valverde (1963) y Delibes (1979) y asumiendo como extintas en los años 60 la mayoría de las pequeñas poblaciones aisladas que Rodríguez y Delibes (1990, 2002, 2004) consideraron presentes en los 80. Los autores compararon sus resultados con la distribución obtenida mediante cuestionarios entre 1950 y 1988 por Rodríguez y Delibes (1992,2002, 2004) concluyendo que los datos obtenidos por avistamientos sobrestimaron la distribución del lince ibérico infravalorando la severidad del declive de la especie. De manera semejante, Sarmento y colaboradores (2009) realizaron entre 2002 y 2003 un sondeo intensivo de lince ibérico en Portugal buscando excrementos, realizando análisis genéticos a los mismos para confirmar la pertenencia a la especie y completando dicha aproximación con campañas de fototrampeo. Sarmento y colaboradores no encontraron ninguna prueba de la existencia de lince en áreas donde Ceia y colaboradores (1998) habían identificado mediante la técnica de recopilación de avistamientos cinco poblaciones de entre 40 a 53 individuos entre 1994 y 1997.

De esta forma, el uso de información de dudosa veracidad para establecer la distribución y abundancia de las poblaciones de lince ibérico llevó a una sobreestimación significativa de las mismas y falló en la identificación de la magnitud de su declive (Gil y McCain 2010). Este hecho dio lugar a un retraso significativo en el comienzo de las acciones de conservación necesarias para su recuperación, permitiendo que las poblaciones de lince ibérico llegaran al umbral de la extinción. A pesar de la cuestionable validez de los avistamientos para estimar con precisión la distribución y abundancia del lince ibérico y otras especies (McKelvey *et al*. 2008; Gil y McCain 2011), estudios basados en este tipo de datos han sido y siguen siendo utilizados en la actualidad como base para 1) enfocar actuaciones de proyectos de conservación (Guzmán *et al*. 2004; CBC 1997), 2) estudios que establecen la categoría de amenaza de la especie (UICN 2001), 3) estudios que reconstruyen su distribución (Clavero y Delibes 2013) y 4) modelos de favorabilidad ambiental para el lince ibérico, incluso del posible efecto del cambio climático sobre sus poblaciones (Real *et al*. 2009; Barbosa y Real 2010; Fordham *et al*. 2013) en las que se sugieren importantes medidas de gestión para la especie.

Planteamiento y contribución de la tesis.

Contexto general

En febrero de 1999 se aprobó la Estrategia de Conservación del lince Ibérico, en la que uno de sus objetivos prioritarios era "subsanar con urgencia el insuficiente conocimiento sobre la abundancia y distribución del lince Ibérico, necesario para el diseño y adopción de medidas de conservación", (MMA 1999). Con este motivo, en el año 2000 se inicia el "Censo-diagnóstico de las poblaciones de lince ibérico en España" (Guzmán *et al*. 2004). Paralelamente y de forma coordinada se realizó en Portugal un estudio equivalente utilizando el mismo diseño y metodología (Guzmán *et al*. 2004; Sarmento et al. 2009). En esta ocasión, la información para establecer la distribución y abundancia de la especie se realizó con información obtenida mediante la búsqueda de excrementos y su posterior análisis genético (Palomares 1999; Palomares *et al* 2002) y mediante fototrampeo (Karanth y Nichols 1998; Moruzzi *et al*. 2002). Ambos métodos tenían por objeto eliminar las fuentes de error habituales en la identificación de la presencia de la especie. En este contexto se abordó la realización de esta tesis doctoral cuyos planteamientos y principales logros se describen a continuación.

El uso de cámaras trampa.

El uso de cámaras trampa ya había demostrado ser muy eficiente para la detección de especies de mamíferos huidizos (Cutler y Swann 1999), y había sido aplicado con éxito para estimar tamaños poblacionales de ese tipo de especies, siempre y cuando los ejemplares fueran reconocidos individualmente como el tigre (*Panthera tigris*; Karanth y Nichols 1998), el leopardo de las nieves (*Uncia uncia*; Jackson *et al*. 2006) o el ocelote (*Felis pardalis*; Trolle y Kéry 2003). Las estimas poblacionales de lince ibérico previas se habían basado en métodos como la recopilación de avistamientos (Rodriguez y Delibes 1992) o la búsqueda de huellas y excrementos (Palomares *et al* 1991). Sin embargo, teniendo en cuenta que el lince ibérico es el felino más amenazado del mundo, era necesario obtener estimas lo más rigurosas y precisas posibles, capaces de detectar rápidamente cambios en la población y por lo tanto permitir la adopción de rápidas medidas de gestión si fuera necesario. Por esta razón en el **capítulo 1** se plantea el objetivo de determinar la validez de las técnicas de fototrampeo para la detección de lince ibérico, y para estimar sus poblaciones mediante el uso de análisis de captura recaptura. Este estudio se desarrolló en el marco del citado proyecto de "Censo-diagnóstico de las poblaciones de lince ibérico en España". Probablemente este fue el estudio con mayor esfuerzo de fototrampeo realizado hasta la fecha (543 estaciones de fototrampeo; 16.290 trampas/noche). Se muestreó prácticamente la totalidad del área de distribución del lince ibérico en el área de Doñana. Los resultados demostraron que al igual que con otros felinos, la aplicación de análisis de captura recaptura a datos obtenidos mediante fototrampeo son adecuados para la estima de abundancia de las poblaciones de lince ibérico. La estima de la población de esta especie en el área de Doñana arrojó una cifra de alrededor de 26 linces mayores de un año, lo que implicó una notable reducción de sus efectivos desde la década de los 80, y la constatación de la crítica situación de la especie en el área de Doñana.

Utilidad de los atrayentes en fototrampeo.

Durante el proceso de publicación del trabajo descrito arriba se creó un intenso debate con los revisores respecto a si el uso de atrayentes en las campañas de fototrampeo era correcto o no, y si podría tener algún efecto negativo sobre las estimas. Este debate ya había surgido previamente con otros colegas en intervenciones en congresos y foros similares. Sin embargo, no existía literatura científica que apoyara una u otra postura. Los atrayentes habían sido utilizados en estimas poblacionales basadas en captura-recaptura de mamíferos, incluyendo felinos (Trolle y Kéry, 2003; Henschel y Ray 2003). Otros estudios no utilizaron atrayentes aludiendo posibles efectos sobre la probabilidad de captura de los individuos lo cual podría afectar negativamente a las estimas (Dillon y Kelly 2007). Sin embargo, para incrementar la precisión de las estimas es importante aumentar la probabilidad de detección de los individuos (Karantn y Nichols 2002), lo cual puede conseguirse mediante el uso de atrayentes, como ha sido descrito para el lince ibérico (Guil *et al.* 2010).

En este contexto, el **capítulo 2** plantea el objetivo de valorar el efecto del uso de atrayentes sobre la capacidad de las cámaras trampa para detectar individuos de lince ibérico y su efecto sobre las subsiguientes estimas poblacionales. Se creó una red de estaciones de fototrampeo en las que se alternaba las estaciones con y sin atrayentes. En los resultados se observó que el número de linces detectados en las estaciones con atrayentes (n=9) fue mayor que los detectados en las estaciones sin atrayente (n=5). A su vez, la probabilidad de captura (P=animales detectados/ estima poblacional) fue mayor en las estaciones con atrayente (p=0.9) que sin atrayente (p=0,5), lo que mejoró la exactitud de las estimas obtenidas. En conclusión, los resultados obtenidos apoyan la utilidad de los atrayentes y confirman que su uso incrementa la efectividad, precisión y eficiencia de las estimas de abundancia mediante captura-recaptura para el lince ibérico.

Tras la finalización del citado “censo-diagnóstico” se estimó que la población de lince ibérico en la Península Ibérica estaba compuesta por una población comprendida entre 84 y 143 individuos (excluyendo los cachorros menores de un año) y entre 26 y 30 territorios de hembras reproductoras. Su distribución se restringía a unos 500 km2 (figura 2), divididos en 2 únicas poblaciones reproductoras en Doñana y Andújar-Cardeña (Sierra Morena Oriental), constatándose su extinción en Portugal (Guzmán *et al* 2004, Sarmento *et al* 2009). La extrema situación de la especie condujo a declararla "En peligro crítico " por la UICN (2001).

Los excrementos como índices de abundancia.

A principios de siglo XXI, evitar la extinción del lince ibérico pasaba ineludiblemente por la conservación de las dos únicas poblaciones existentes en la Península. Para ello se desarrollaron una serie de proyectos de conservación enfocados a incrementar la capacidad de carga y reducir las amenazas directas que actuaban sobre la especie. En los últimos años, como resultado de los programas de conservación desarrollados, el área de distribución y el número de ejemplares de las poblaciones de lince ibérico se han incrementado notablemente (Simón et al 2012). Ante este escenario de expansión, el seguimiento de sus poblaciones mediante fototrampeo puede llegar a ser logística y económicamente inabarcable. Por eso, en el **capítulo 3** se estudia la efectividad de la utilización de los conteos de excrementos, un método más económico, para establecer la abundancia y evolución de las poblaciones de lince ibérico a gran escala. Para ello, se planteo una comparativa de ambos métodos (conteo de excrementos vs fototrampeo) en la que se abordaron dos aspectos: En primer lugar, se comprobó si el método de conteo de excrementos es capaz de predecir las densidades de lince ibérico establecidas mediante fototrampeo. Y en segundo lugar, se evaluó el coste económico del monitoreo mediante fototrampeo y mediante conteo excrementos. Los resultados sugirieron que este método proporciona un índice fiable y económico de la distribución espacial de la densidad de las poblaciones de lince ibérico cuando era contrastado con la información obtenida mediante un método más caro como el fototrampeo. El conteo de excrementos se presenta como una alternativa prometedora para seguir la evolución de la abundancia de esta especie en grandes áreas donde el uso de métodos como el fototrampeo puede llegar a ser logística y económicamente inviables.

Tasas de mortalidad.

Una de las principales líneas de actuación de los proyectos de conservación se basó en la reducción de las principales causas de mortalidad conocidas. Las acciones de conservación destinadas a reducir la mortalidad de la especie se establecieron en función de la información previa existente que provenía de estudios llevados a cabo en el siglo pasado (entre 1950 a 1989) y había sido obtenida a partir de diversas fuentes, como ejemplares de museos (García-Perea 2000), entrevistas personales (Rodríguez y Delibes 2004) o radioseguimiento (Ferreras *et al*. 2004). Pero como los proyectos de conservación del lince ibérico buscaban disminuir la magnitud de estas amenazas a través del uso del conocimiento de la ecología de lince ibérico y su manejo adaptativo, era necesaria la continua actualización de este conocimiento. El **capítulo 4** se plantea el objetivo general determinar las tasas de mortalidad de lince ibérico y sus causas en toda su área de distribución con el fin de evaluar y mejorar las medidas de conservación, determinar la importancia relativa de las diferentes causas entre las dos poblaciones de lince ibérico y analizar los posibles cambios en las tasas de mortalidad y sus causas en los últimos 20 años. Dado que la probabilidad de detección individuos muertos varían en función de las diferentes causas de mortalidad (Bischof *et al*. 2009; Liberg *et al*. 2012), el método más adecuado para cuantificar las tasas de mortalidad en poblaciones de mamíferos es el radioseguimiento (Heisey y Fuller 1985). En la realización de este estudio se utilizaron datos provenientes de 78 individuos radiomarcados (39 de Sierra Morena y 39 de Doñana) entre los años 2006 y 2011. Cada caso de muerte fue evaluado para identificar las causas y se obtuvieron las tasas anuales de mortalidad (TAM) mediante la función no paramétrica de incidencia acumulada (Heisey y Fuller 1985). La mortalidad media obtenida fue de 0.16±0.05 (0.19±0.09 en Sierra Morena y 0.12±0.07 en Doñana). Las enfermedades fueron la principal causa de muerte para toda la población en su conjunto (0.06 ± 0.003) y para la población de Doñana en particular (0.07±0.05). La caza ilegal fue la principal causa de muerte en la población de Sierra Morena (0.06±0.05). Las tasas anuales de mortalidad de ambas poblaciones obtenidas en este estudio fueron menores que las obtenidas 20 años atrás por Ferreras y colaboradores (1992) en el área de Doñana, único estudio previo de mortalidad de lince ibérico realizado en base a datos obtenidos con radioseguimiento y por lo tanto comparable. Los resultados sugieren que la mejor estrategia para la conservación de esta especie es concentrar las acciones en la disminución de los efectos mortales de las enfermedades y la caza furtiva. Dado que la mayor incidencia de las enfermedades en la población de Doñana podría estar provocada por inmunosupresión debida a un alto grado de consanguinidad (Godoy *et al*. 2009; Palomares *et al*. 2012), se recomendó continuar con el manejo genético destinado a aumentar la diversidad genética de esta población.

Incidencias con animales domésticos.

Uno de los focos de mortalidad detectada en la población de Sierra Morena fue consecuencia de la mortalidad provocada por algunos propietarios de ganado doméstico como represalia a los ataques sobre sus animales. Este tipo de conflicto entre humanos y lince ibérico no había sido documentado en la literatura científica previamente. Como consecuencia de la detección de un incremento en el número de ataques sobre los animales domésticos a medida que la especie recolonizaba nuevas áreas semiurbanizadas, se creó, en el marco de los proyectos Life, un programa de prevención y compensación con el objetivo de minimizar la hostilidad de los habitantes hacia el lince. En el **Capitulo 5** se describen 6 años de episodios de predación sobre gallinas y corderos en el área de Andújar-Cardeña (Sierra Morena) y sus consecuencias en la conservación de la especie. Los resultados indican que la mayoría da los ataques se produjeron sobre aves de corral (78%) y en menor medida sobre corderos. A pesar de ello, las pérdidas económicas fueron mayores en los casos de ataques sobre corderos. En el caso de los ataques sobre aves de corral, tras el pago de los daños y el correcto cerramiento de los gallineros, el conflicto desapareció casi en la totalidad de los casos. Sin embargo, en el caso de los ataques sobre corderos, principalmente sobre aquellos rebaños manejados en extensivo, las pérdidas económicas fueron mayores (720±360 € por ataque sobre rebaños en extensivo vs 128,5±103,1 € por ataque sobre aves de corral) y los ataques continuaron sucediendo. Es necesario en este caso ensayar métodos de prevención que reduzcan el impacto de los ataques de lince sobre los corderos para minimizar así el conflicto con los ganaderos. Aunque el problema de la depredación sobre corderos en el área de Andújar-Cardeña no parece un problema importante por su magnitud (tan solo hay dos rebaños en extensivo en el área), lo potenciales conflictos que pudieran darse en nuevas áreas con mayor carga ganadera debería ser tenido en cuenta como variable a la hora de establecer la idoneidad de nuevas áreas de reintroducción.

Historia de la gestión para la recuperación.

En el **capítulo 6** se describen los esfuerzos de conservación y sus el efecto sobre las poblaciones del lince ibérico en un plan continuo de conservación y recuperación de las poblaciones de lince estructurado principalmente alrededor de los proyectos Life. Estos comenzaron en el año 2002 con el proyecto Life "Recuperación de las Poblaciones de Lince Ibérico en Andalucía (2002-2006)" y tuvo continuación con el proyecto Life "Conservación y reintroducción del Lince Ibérico en Andalucía (2006-2011)". A estos proyectos hay que sumarle los que el Organismo Autónomo de Parques Nacionales (OAPN) del Ministerio de Medio Ambiente, Rural y Marino, viene desarrollando en las fincas de Lugar Nuevo y Contadero Selladores (Jaén) desde el año 2002 (Guzmán *et al* 2012), y la puesta en marcha del programa de cría en cautividad del lince ibérico (Vargas *et al* 2009).

Las principales amenazas que impedían la recuperación de la especie eran: 1) la baja abundancia de conejo, 2) la mortalidad no natural y por enfermedades, 3) la baja variabilidad genética y el 4) bajo número de poblaciones (Rodríguez y Delibes 1992; Guzmán *et al*. 2004; Godoy *et al*. 2009). Por esto, las principales líneas de actuación de estos proyectos, destinadas a minimizar la amenazas que afectaban a la especie fueron: 1) El incremento de la capacidad de carga de las áreas de presencia, principalmente mediante la recuperación de las poblaciones de conejo silvestre, 2) reducción de la mortalidad no natural, 3) establecimiento de un programa sanitario, 4) reforzamiento genético de la población de Doñana y 5) creación de nuevas poblaciones mediante reintroducción. Gran parte del área de distribución del lince ibérico se incluía en fincas destinadas a caza mayor y/o menor, la mayoría de titularidad privada (80%). Por esta razón, para el desarrollo de las acciones de conservación de las diferentes líneas de actuación, fue necesario la elaboración de acuerdos de colaboración con los titulares de estos terrenos (180.000 ha en total). La efectividad de las acciones fue evaluada mediante un programa de seguimiento de las poblaciones de lince ibérico (principalmente mediante fototrampeo; ver secciones anteriores) y de conejo silvestre. Entre los años 2002 y 2010 el número mínimo de linces detectados mediante fototrampeo pasó de 93 a 252, y el área ocupada por la especie se incrementó de 29,300 a 70.300 ha (estimado en base a datos de fototrampeo y de muestreos sistemáticos de excrementos de la especie). La población de Doñana pasó de 34 individuos distribuidos en 17,400 ha a 73 individuos distribuidos en 44,300 ha. Además se inició el programa de refuerzo genético de la población de Doñana mediante la translocación de 4 ejemplares provenientes de la población de Sierra Morena. La población de Sierra Morena también vio incrementada su población tanto en número (59-179) como en área ocupada (11.900 – 26.000 ha), además de contar con dos nuevas poblaciones creadas mediante reintroducción.

Durante la última década, la evolución de las poblaciones de lince ibérico ha puesto de manifiesto que es posible corregir la situación de partida, con alrededor de 100 individuos repartidos en dos núcleos, hacia una situación más optimista, con más de 300 ejemplares en 2013 repartidos en cuatro poblaciones: una en Doñana-Aljarafe y las otras tres en Sierra Morena, conformadas en un sistema metapoblacional con una buena conexión entre subpoblaciones (Fuente: www.lifelince.org). A pesar de ello, el escenario en el que se encuentra la especie aún es inestable. Algunos de los conocidos factores de amenaza podrían desencadenar un proceso de extinción en cualquiera de las poblaciones. Así, la escasez de efectivos numéricos de la especie y de poblaciones, la pérdida de variabilidad genética (Godoy et al*.,* 2009), el riesgo de contraer enfermedades (López *et al.* 2009), la mortalidad no natural y las enfermedades víricas del conejo (Garrote 2013) continúan amenazando al lince ibérico. La supervivencia de la especie a largo plazo requiere, por lo tanto, la aplicación de medidas de conservación de manera continua y eficaz basada en información fiable. Este es el contexto en el que se ha realizado la presente tesis doctoral cuyos objetivos explícitos paso a resumir a continuación.

OBJETIVOS.

Los trabajos que componen esta tesis doctoral se han desarrollado en el marco de los proyectos "Censo-Diagnóstico de las poblaciones de lince ibérico (*Lynx pardinus*) en España", proyecto LIfe "Recuperación de las Poblaciones de lince Ibérico en Andalucía" y Proyecto Life Naturaleza "Conservación y reintroducción del lince ibérico (*Lynx pardinus*) en

Andalucía.2006-2011". Cada uno de los aspectos tratados en esta tesis doctoral nace con el objetivo de cubrir alguna necesidad creada en el contexto de los proyectos mencionados, como conocer la distribución y abundancia de la especie, valorar la efectividad de las medidas de conservación desarrolladas, obtener la información necesaria para establecer, reorientar o confirmar líneas de actuación y porque no decirlo, para defender los resultados del trabajo realizado en los distintos proyectos ante algunos sectores escépticos de la sociedad. Los objetivos de esta tesis doctoral son los siguientes:

- Determinar la validez de las técnicas de fototrampeo para la detección de lince ibérico y para estimar sus poblaciones mediante el uso de análisis de captura recaptura (**capítulo 1**)
- Valorar el efecto del uso o no uso de atrayentes sobre la efectividad de las cámaras trampa para detectar individuos de lince ibérico y su efecto sobre las subsiguientes estimas poblacionales (**capítulo 2**).
- Evaluar la precisión de los índices de abundancia obtenidos mediante conteo de excrementos como estimadores de densidad de lince ibérico, y su potencial uso como alternativa económicamente rentable frente al uso de cámaras trampa. (**capítulo 3**)
- Determinar las tasas de mortalidad de lince ibérico y sus causas en toda su área de distribución con el fin de evaluar y mejorar las medidas de conservación, determinar la importancia relativa de las diferentes causas de mortalidad entre las dos poblaciones de lince ibérico y analizar los posibles cambios en las tasas de mortalidad y sus causas en los últimos 20 años (**capítulo 4**).
- Exponer los resultados de 6 años de seguimiento de los eventos de predación de lince ibérico sobre ganado doméstico en la Sierra de Andújar, y describir el programa de prevención y compensación desarrollado para minimizar los daños producidos a los ganaderos y evitar muertes de linces por estas causas (**capítulo 5**).
- Proporcionar una visión general de las iniciativas de conservación desarrolladas y de la situación del lince ibérico en la primera década del siglo XXI (**capítulo 6**).

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CAPITULO 1

Estima de las poblaciones de lince ibérico (*Lynx pardinus*) del área de Doñana, SE de España, mediante el análisis de captura-recaptura con datos de fototrampeo.

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Estima de las poblaciones de lince ibérico (*Lynx pardinus*) del área de Doñana, SE de España, mediante el análisis de captura-recaptura con datos de fototrampeo.

El lince ibérico (*Lynx pardinus*) presenta una distribución geográfica muy restringida, limitada únicamente a la península ibérica. El último sondeo a nivel nacional reportó menos de 200 individuos, distribuidos en dos áreas aisladas (Andújar-Cardeña y Doñana), y en consecuencia, el lince ibérico fue catalogado por la Unión Internacional de Conservación de la Naturaleza como "en peligro crítico". En este estudio, se estima la población de lince ibérico del área de Doñana aplicando análisis de captura-recaptura a datos obtenidos mediante fototrampeo. El modelo de diferencias individuales en la probabilidad de captura (Mh) arrojó una estima de 26 linces ibéricos (SE=5,26) de más de un año de edad. Podría existir un pequeño sesgo en la estima debido a la presencia de individuos dispersantes en el área de estudio que pudieron no ser detectados. Este estudio revela: 1) una reducción del número de ejemplares desde los años 80 (45 individuos), por debajo del límite teórico de la viabilidad genética, 2) cambios en la distribución espacial de la especie en el área, y 3) como en otros carnívoros, el método de análisis de captura-recaptura con datos de fototrampeo es aplicable para estimar el tamaño de las poblaciones de lince ibérico.

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ORIGINAL PAPER

Estimation of the Iberian lynx (*Lynx pardinus*) population in the Doñana area, SW Spain, using capture–recapture analysis of camera-trapping data

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Abstract The Iberian lynx (*Lynx pardinus*) has a highly restricted geographic distribution, limited even within the Iberian Peninsula. The last national survey reported less than 200 remaining individuals, distributed in two isolated areas—Andújar-Cardeña and Doñana—and in consequence, the Iberian lynx was listed by the International Union for Conservation of Nature as "Critically Endangered". In this study, we estimate the Iberian lynx population size in the Doñana area using capture–recapture analysis of camera-trapping data. A model with different capture probability for each individual (M_h) yielded an estimate of 26 Iberian lynxes (SE=5.26) more than 1 year old. It is considered that a small slant in the estimation of the number of individuals could exist due to the presence of dispersers inside the study area that were not detected. Our study shows: (1) a reduction in number since the 1980s (45 individuals), and falling below the theoretical threshold of genetic viability, (2) changes in the species' spatial distribution in this area, and (3) as for other carnivore species, photographic capture–recapture methods are applicable for estimating the size of Iberian lynx populations

Keywords *Lynx pardinus* · Iberian lynx · Camera trapping · Capture–recapture · Population estimates · Doñana

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Introduction

Ineffective carnivore survey methods limit the ability of managers and researchers to make appropriate research conclusions and management recommendations (Heilbrun et al. 2006). A technique that estimates density (Lancia et al. 1994), detects changes over time (Gibbs 2000), and considers the welfare of individual animals (Gibbs 2000; Murray and Fuller 2000; Peterson et al. 2003) would greatly enhance the ability to monitor and manage populations.

The use of camera traps to detect elusive mammals, such as carnivores, has proven to be highly efficient (Cutler and Swann 1999), and some recent studies have proven the great potential that this method can provide for estimating population sizes of secretive, but individually recognisable animals. Populations of tiger (*Panthera tigris*; Karanth and Nichols 1998), leopard (*Panthera pardus*; Henschel and

Ray 2003), snow leopard (*Uncia uncia*; Jackson et al. 2006), and ocelot (*Felis pardalis*; Trolle and Kéry 2003) have been successfully estimated using capture–recapture analysis of camera-trapping data.

The Iberian lynx (*Lynx pardinus*) population, limited both to and within the Iberian Peninsula (Mitchell-Jones et al. 1999), has declined markedly over the last century (Graells 1897; Cabrera 1914; Valverde 1963). During the late 1980s, a national survey estimated a total population size of only approximately 1,000 adult individuals (Rodríguez and Delibes 1992). This situation was mainly due to wide-scale vegetation removal and transformation, human-caused mortality, and the decline of its main prey, the wild rabbit (*Oryctolagus cuniculus*), due to the impact of the myxomatosis virus (Rodríguez and Delibes 1992, 2003). During the late 1980s, the Iberian rabbit populations were also seriously affected by rabbit hemorrhagic disease (RHD; Villafuerte et al. 1994), and this could have affected lynx populations via the severe decline of its specialised prey. Indeed, a national survey carried out in 2002 (Guzmán et al. 2004) reported an absolute number of less than 160 individual Iberian lynxes for the whole of Spain, distributed in just two isolated areas: Andújar-Cardeña and Doñana. In consequence, the species was listed by the International Union for Conservation of Nature (IUCN) as "Critically Endangered" (IUCN 2002, 2007). This has led to the implementation of several management measures which aim to stabilise the population and in the future, try to reverse this situation (see Simón 2008).

Population estimates in the Doñana area showed that the number of individuals also declined (Rau et al. 1985; Palomares et al. 1991; Ferreras 2001; Guzman et al. 2004) as in the rest of its distribution range and for the same factors mentioned above.

Previous censuses in the Doñana area were based on intensive searches for signs of lynx presence (tracks and droppings) in order to estimate the population (Palomares et al. 1991; Guzman et al. 2004). The authors assumed a direct relationship between the index of signs abundance and lynx numbers. Palomares et al. (1991) estimated there were 45 (40–50) individuals (excluding cubs still tended by their mother) in the Doñana area in the late 1980s, while Guzmán et al. (2004) estimated 36–42 lynxes there in 2002.

These methods provided a good approximation of the population size. However, considering that the Iberian lynx is the most endangered feline in the world, it is necessary to obtain as rigorous and accurate estimates as are possible, with methods capable of quickly detecting population changes and thus allowing the adoption of emergency management measures when required.

The aim of the present study was to determine whether the use of camera-trapping techniques is applicable to the Iberian lynx, a species with a very limited population and restricted distribution area, as well as whether this method can also be applied to estimate its population using capture–recapture analysis.

These conclusions are crucial for establishing an adequate monitoring programme which will allow the design and adoption of further conservation measures.

Materials and methods

Study area

The study area is located in SW Spain, including Doñana National Park, Doñana Natural Park, and the peripheral zone (Fig. 1). The area is bordered on the south and west by the Atlantic Ocean, to the east by the Guadalquivir River, and to the north by the alluvial plain of the River Tinto and the intensively cultivated high ground of Aljarafe (Anon 1989).

The area is generally flat, but with some undulations in the north, and the eastern third is largely seasonally flooded marshland. The climate is sub-humid Mediterranean with mild, wet winters and hot, dry summers and the annual rainfall is between 500 and 1,000 mm (Rivas-Martínez 1987).

Seven vegetation units can be distinguished: Mediterranean scrub, Eucalyptus spp. plantations, pine plantations, forested pastureland, marsh, beaches and dunes, and cultivated land. Outside the protected areas, irrigated agriculture and coastal tourism have developed to a large degree over the last two decades, with a corresponding considerable increase in human impact.

In most of the National Park, human access is restricted to researchers and wardens, and hunting is strictly forbidden. Conversely, outside the National Park boundaries, levels of human access depend on land owners and game hunting is frequent.

Camera trapping

The fieldwork was undertaken between November 2002 and February 2003 by four teams of two to four people each. Photographs were taken using 35 mm cameras with a data register and automatic flash. The cameras were modified to allow activation via an external 25×25 cm pressure plate, positioned 170 cm away, and triggered when stepped on by an animal. Lynx urine obtained from captive animals was used as the lure, and placed on an inert support 50 cm above the ground and adjacent to the pressure plate. This attractant was replaced every 3 days (2.5 ml/visit) according to previous studies about the efficiency of this lure in attracting lynxes (Garrote et al. 2001). Attractants are often deployed by researchers at camera-trap sites to

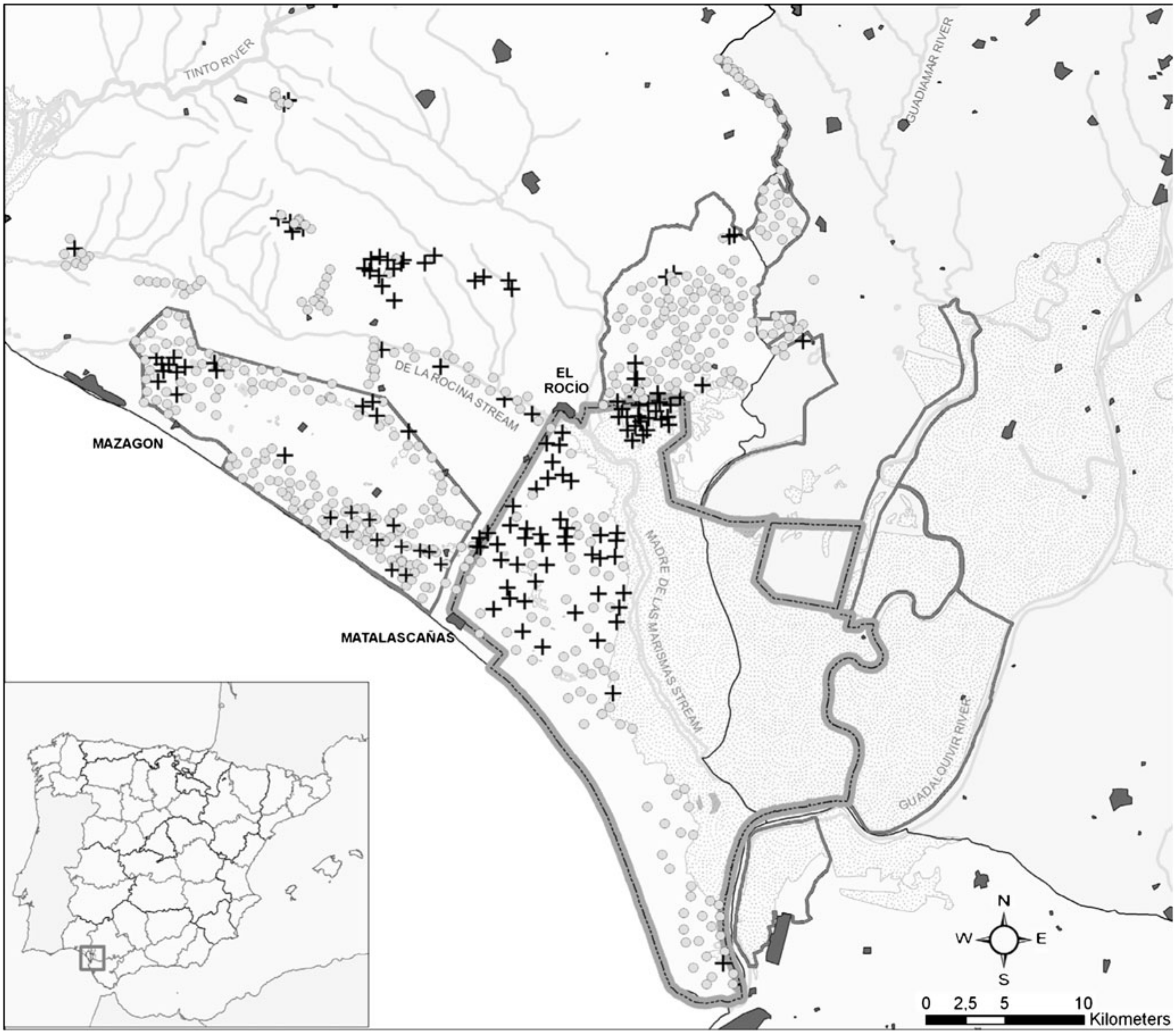

Fig. 1 Survey area in Doñana National Park (*broken line*), Doñana Natural Park (*continuous line*), and peripheral area showing camera trap layout (*grey dot*). Camera trap with Iberian lynx photograph (*plus sign*)

encourage visits by carnivores (Trolle and Kéry 2003; Zielinski and Kucera 1995). As long as the effort and baiting pattern/protocol is standardised, the use of such attractants does not have any major sampling implications and poses no statistical problem for capture-recapture estimates (Henschel and Ray 2003, and see Trolle and Kéry 2003).

The entire area potentially used by Iberian lynx was surveyed inside both the National and Natural Park boundaries (Fig. 1), covering all but the marsh, beach, dunes, cultivated land, and pastures. In the peripheral areas, the cameras were placed at those sites where signs had been detected within the previous year (scats, tracks, road casualties). The main areas inside the National Park not included in this study were marshlands; inside the western Natural Park, the areas excluded were temporary pools (the Abalario lagoons) containing water during our study. Neither of these habitats was used by lynx within both the National and Natural Parks.

The distance between camera traps was 400–800 m, producing a density of >4 traps per 450 ha, the smallest occupied home range size known for any given age–sex class (an adult female lynx breeding in a high rabbit density situation; Ferreras et al. 1997; Palomares et al. 2001). Consequently, individuals of other age–sex classes will be exposed to a greater number of traps (Otis et al. 1978; Karanth and Nichols 2002). In order to obtain an adequate number of lynx captures, the camera-trap locations were chosen to maximise capture probabilities (Karanth and Nichols 1998). Each camera remained continuously active during the entire survey period for each block (see "Statistical methods" section).

All lynxes photographed were individually identified through a comparison of distinguishing natural body marking (spots), as made in other species such as tigers, leopards, and ocelots (Karanth and Nichols 1998; Henschel and Ray 2003; Trolle and Kéry 2003).

Statistical methods

The study area was divided into two blocks (east and west) which were sampled sequentially (with a 10-day gap between them to allow for camera relocation) for the same total time period (N=30 days). Capture histories were developed for each lynx older than a year identified by the camera trapping. Cubs were not included in the analysis because they could have lower capture probabilities (Karanth and Nichols 1998). The capture history consisted of a string of ones and zeros indicating whether the individual was camera trapped (1) or not (0) during each "trapping occasion". The capture history data of the first sampling day, in each of the two blocks were combined to form one sampling occasion (Karanth and Nichols 2002; Soisalo and Cavalcanti 2006). The same procedure was used for each of the remaining days within the 30-day sampling period.

The capture histories data were analysed using the MARK software (White and Burnham 1999), developed to implement closed-population capture–recapture models. The MARK programme produces abundance estimates from seven models that differ in their assumptions about capture probability. Individual heterogeneity, behavioural response, and time are used as the sources of variation in the capture probabilities.

Model M_0, assumes a constant capture probability across all occasions and animals. Model M_t (time) assumes that capture probability varies between occasions. Model M_b (behaviour) assumes that capture probability differs for animals that have, or have not been captured previously. Model M_h (heterogeneity) assumes that each animal had its own probability of being captured. In addition, MARK allows estimation under four models that are pairwise combinations of these sources of variation in capture probability (Models M_{bh}, M_{th}, M_{tb}, M_{tbh}).

To identify an adequate model for estimation, we used the goodness-of-fit test, between-model test, and the model selection algorithm (Otis et al. 1978; Rexstad and Burnham 1991) provided in MARK.

These models are designed for closed populations, so assume no changes during the study. To ensure that our population was closed, the best approach was to make the period of study as short as possible (Otis et al. 1978). Thus, we only use the first 30 days from each phase of camera trapping for the analysis, and the total survey period was consequently 70 days. This was a short trapping period to assume that the population stayed stable over the study period (Karanth and Nichols 1998; Trolle and Kéry 2003; Silver et al. 2004).

The area sampled, and the area occupied by lynx was defined by an outer buffer strip equal to the one-half of the mean maximum distance Iberian lynx travelled between camera-trap stations placed and between camera trap stations with Iberian lynx photograph, respectively (Karanth and Nichols 2002).

Results

During the study period, 543 trapping stations were installed for 30 days each, 280 in the east block and 263 in the west block. The total camera-trapping effort leads to 16,290 camera-trapping nights. Twenty different Iberian lynx (nine males and 11 females) were photographed a total of 129 times at 116 different camera stations. Some individuals were recaptured multiple times and at multiple camera stations within one survey day. Because closed-population capture-recapture models consider only one recapture per "trapping occasion", a total of 87 positive trapping occasions were considered for the total of 129 captures (Table 1).

The number of trapping occasions for each individual varied from 1 to 19 (Table 1), indicating a notable individual variation in capture probability. Except for one female, all of those captured had been photographed previously in earlier surveys undertaken since 1999, helping the task of ageing and sexing each.

The cumulative curve of individuals "captured" during the survey stabilised after 20 days (Fig. 2). This signifies that no new individuals were photographed after day 20. Given this information, we deduce that the length of the survey was adequate for the aims of our study.

The resulting population size estimate was 26 Iberian lynx (SE=5.26) more than 1 year old. The model selection algorithm in MARK selected the model M_h, with a different capture probability for each individual. The estimated capture probability per occasion and individual was 0.1115, and the estimated probability of catching a lynx at least once during the entire study period is given by the ratio of total number of animals caught to the estimated population size, 20/26=0.77 (Karanth and Nichols 1998).

To test for a possible differential effect of the attractant on the two sexes or on different age classes which could bias the final estimates, the population estimates were made separately for males and females, and for adult and non-

Table 1 Summary of camera-trapping results

Individual	Trapping occasions	Age	Sex
IL01	1	Adult	Female
IL02	5	Adult	Female
IL03	5	Adult	Female
IL04	1	Adult	Female
IL05	3	Adult	Female
IL06	1	Adult	Female
IL07	1	Adult	Female
IL08	1	Adult	Male
IL09	3	Adult	Male
IL10	1	Adult	Male
IL11	1	Adult	Male
IL12	5	Adult	Male
IL13	19	Indet.	Female
IL14	2	<3 years	Female
IL15	1	<3 years	Male
IL16	15	<2 years	Female
IL17	12	<2 years	Female
IL18	7	<2 years	Female
IL19	2	<2 years	Male
IL20	1	<2 years	Male

Number of trapping occasions, age, and sex of each individual photographed

adult lynxes. Following the recommendations of Karanth and Nichols (2002) the M_h was used since this most probably better reflects the behaviours of solitary cats, and would provide a reasonable model for lynx capture probability (Kelly et al. 2008). This makes biological sense since most cats exhibit some degree of territoriality, with home range size and trap access varying and depending on the individual's social position and spatial location in the landscape (Henschel and Ray 2003; Karanth and Nichols 1998, 2002; Silver et al. 2004). In addition to expecting

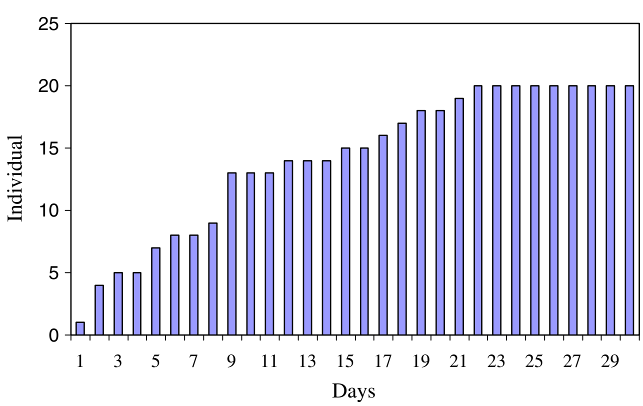

Fig. 2 Cumulative curve for photo-identified Iberian lynx. Days from the start of camera-trapping (*x*-axis) versus photo-identified individuals (*y*-axis)

heterogeneity of capture probabilities, the use of M_h is preferable, because the jackknife estimator (Burnham and Overton 1979) for this model is robust to deviations from underlying model assumptions, and has performed well in simulation studies (Otis et al. 1978; Burnham and Overton 1979).

The population estimates obtained for lynx more than 1 year old were 14 females (SE: 2.5697) and 12 (SE: 3.5136) males. The sum of both estimates coincides with that obtained from the combined matrix of males and females.

The population estimates obtained for adult lynxes (≥3 years) were 15 individuals (SE: 3.513), and ten individuals (SE: 2.053) for non-adults (<3 years). The sum of both estimates is only one lynx less than the estimate obtained from the combined matrix.

The mean maximum distances moved by individual Iberian lynx between successive captures were 2.04 km, providing an outer buffer-strip width of 1.02 km. Thus, the effectively sampled area was 64,803 ha. The area occupied by the lynx was 25,067 ha.

Discussion

Iberian lynx population situation

Our results show that in the Doñana area, the total Iberian lynx population size is around 26 individuals older than a year, occupying 25,067 ha. Despite the methodological differences with the Palomares et al. (1991) study, where 45 individuals were reported, a decline in the number of lynxes since the 1980s can be seen.

A few years after the appearance of RHD during the early 1990s, the estimated rabbit population decrease was about 40% (Villafuerte et al. 1994). At present, the wild rabbit is almost completely absent in 75% of the entire area (Guzmán et al. 2004). This rabbit population crash appears to be the principal cause of the lynx decline.

Approximately half of the Doñana lynx population lives in only a quarter of its distribution area, precisely where the best rabbit populations are located: along the northern National Park boundary and the western limits of the Natural Park (Guzmán et al. 2004).

This situation reveals a new spatial distribution of lynx in the Doñana area. In the 1980s, approximately 80% of all lynx individuals were found inside the National Park boundaries, another 10% in the adjacent area, and the rest at some distance from it (Palomares et al. 1991). In this study, however, only less than a half of the remaining lynx individuals have been detected inside the National Park, and the species has almost completely disappeared from the southern third of the National Park. Only one photograph has been obtained in this area, of a female whose resident area (where it is regularly detected), is located 20 km away.

The theory states that given the current estimate obtained, the population is not genetically viable (Soulé 1980; Shaffer and Samson 1985). In such small and isolated populations, the loss of genetic variability is accelerated (Franklin 1980), and so makes them extremely fragile. In fact, a recent study indicated that all lynxes necropsied between 1998 and 2003 in the Doñana area presented some degree of immunosuppression (Peña et al. 2006) and membranous glomerulopathy, a progressive disease of immunological origin, was diagnosed in all but one of the animals (Jiménez et al. 2008). The authors postulate a possible genetic predisposition towards the disease, enhanced by inbreeding and a possible connection to an immune-mediated systemic disease.

Applicability of camera-trap surveys

The present study probably represents the largest survey effort ever applied in a camera-trapping study (543 camera traps; 16,290 trapping nights). As a result, practically all of the Doñana area's Iberian lynx population distribution area was surveyed in little more than 2 months.

The estimated average capture probability (0.1115), and the estimated probabilities of missing an animal ($1\text{-}M_t/N<0.25$) are similar to those obtained from other studies on the tiger (Karanth and Nichols 1998), jaguar (Kelly et al. 2008), and ocelot (Trolle and Kéry 2003).

Attractants are commonly used in capture–recapture population estimates, including carnivores (Trolle and Kéry 2003; Henschel and Ray 2003), deer (Curtis et al. 2009), and small mammals (Efford et al. 2005). However, some studies avoid the use of attractants because they can cause heterogeneity in the captures (Jacobson et al. 1997). The model selection algorithm identified M_h as the most appropriate model, showing the existence of heterogeneity in capture probabilities between individuals given the social structure and unequal access to camera traps. In addition, based on our data, we can assume that the attractant used does not produce a significant differential effect neither on sex nor on age classes which would lead to changes in the estimates. Besides the effect of the possible variability between sexes, ages, or individuals is adequately "buffered" by applying the M_h model of individual heterogeneity, which is known to be robust to violation of underlying model assumptions (Otis et al. 1978; Burnham and Overton 1979).

One of the assumptions of capture–recapture analysis is the absence of gaps in the study area that were not surveyed where any individual had zero probabilities of being captured (Karanth and Nichols 1998). Though in this study the entire area potentially used by Iberian lynx was surveyed, there exist areas that were not covered in the camera-trapping survey. These areas correspond with *open areas* (agricultural areas or without bush cover) or areas where rabbit is absent, that are rejected by lynxes and considered inadequate for the establishment of territories and that are used by dispersal individuals only (Palomares et al. 2000). Although the probability that a lynx territory could have existed inside these areas that were not surveyed is small, a disperser may have used them during the study. This fact could suppose a violation of the assumption and therefore could affect to the final estimation.

Our study shows that as with other carnivore species, photographic capture–recapture methods are applicable for estimating the abundance of Iberian lynx populations, as they are a fast, effective, and non-invasive method for establishing the status of these populations.

The deployment of remote cameras offers a helpful means to obtain additional information. Camera trapping makes it possible to establish the limits of the distribution area, to obtain information about the population sex ratio, and occasionally, to detect individuals with poor body condition or which are injured. This permits rapid response action for these individuals, if necessary.

With successive camera-trapping surveys, it would be possible to identify resident lynxes, i.e., those individuals detected within the same area over successive seasons and years (Hemker et al. 1984). This information is especially important in the case of the females, since monitoring resident females is the most reliable means for assessing the trend of a particular population (Karanth and Nichols 2002).

There also appears to be a potential for using long-term camera-trapping surveys to estimate additional population parameters such as survival, mortality, recruitment, and dispersal rates for Iberian lynx, by applying open capture–recapture models that are currently available (Seber 1982; Pollock et al. 1990; Lebreton et al. 1992).

Additionally, remote monitoring reduces adverse effects that may be caused by more invasive methods including complications due to capture, destructive marking techniques, and also reduces behavioural changes due to the capture or marking process (Heilbrun et al. 2006).

Considering our results, we recommend to conduct surveys of at least 1 month length (time necessary to stabilise the cumulative curve), with a density of one trap per 100 ha and covering the biggest area in consecutive stages to cover the whole study area.

Conclusions

As in the rest of its distribution area, the Iberian lynx in Doñana has suffered a decline leaving it in a critical situation, compromising its long-term survival, and placing it on the edge of extinction. Traditionally, the majority of the research studies, as well as conservation work undertaken on the Doñana population, have been carried out within the National Park boundaries (e.g., Ferreras et al. 1997; Lopez-Bao et al. 2008; Palomares et al. 1996, 2001), where higher levels of protection are present and disturbance to the species is minimal. However, given the new spatial distribution shown by the Doñana population, the survival of the species inexorably requires the implementation of adequate management beyond the National Park boundaries. And this implies continuous monitoring of its populations throughout its entire distribution area. This study has revealed the applicability of camera-trap surveys for making rapid, efficient, and non-invasive population estimates of the species. Establishing a repeated and consistent monitoring programme employing camera trapping could be an essential tool to detect population and/or range changes and for properly assessing the effectiveness of conservation investments targeting the Iberian lynx.

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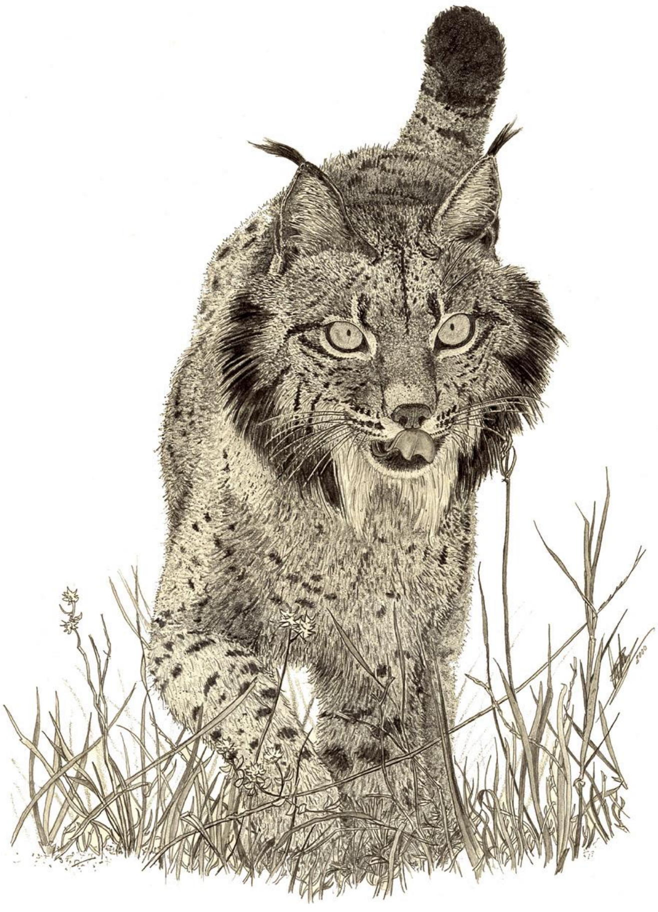
CAPITULO 2

El efecto de los atrayentes en el fototrampeo: un caso de estudio basado en estimas poblacionales de lince ibérico (*Lynx pardinus*).



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El efecto de los atrayentes en el fototrampeo: un caso de estudio basado en estimas poblacionales de lince ibérico (*Lynx pardinus*).

El análisis de captura-recaptura con datos de fototrampeo es un método habitual para estimar la abundancia de felinos silvestres. Dadas las bajas tasas de detección de los felinos, es importante incrementar su probabilidad de detección durante el muestreo. En este estudio, presentamos la eficacia de los atrayentes como herramienta para mejorar la eficiencia de los muestreos con cámaras trampa destinados a estimar poblaciones de lince ibérico. Creamos una red de estaciones de fototrampeo que cubrió el área de estudio en la que se alternaron las estaciones con y sin atrayente. De 10 individuos identificados, cinco fueron detectados en las estaciones sin atrayente (al paso), y nueve, en las estaciones con atrayente. En el 38% de las capturas de las estaciones al paso, y en el 10% de las capturas en las estaciones con atrayente se obtuvieron fotografías inservibles para una correcta identificación de los individuos. La probabilidad total de captura en las estaciones con atrayente fue mayor que la obtenida con las estaciones al paso. Las estimas obtenidas con las estaciones al paso subestimaron el número de linces en comparación con las obtenidas con las estaciones con atrayente. Nuestro estudio refleja como el uso de atrayentes incrementa la eficiencia de las capturas de las cámaras de fototrampeo y consecuentemente, la exactitud de los análisis de captura-recaptura. Los fallos observados en la detección de individuos en las cámaras al paso pueden suponer la violación de las asunciones de las estimas de captura recaptura y provocar errores en las estimas de abundancia.

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TECHNICAL NOTES

The effect of attractant lures in camera trapping: a case study of population estimates for the Iberian lynx (*Lynx pardinus*)

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Abstract Capture–recapture analysis of camera trap data is a conventional method to estimate the abundance of free-ranging wild felids. Due to notorious low detection rates of felids, it is important to increase the detection probability during sampling. In this study, we report the effectiveness of attractants as a tool for improving the efficiency of camera trap sampling in abundance estimation of Iberian lynx. We developed a grid system of camera stations in which stations with and without attractant lures were spatially alternated across known Iberian lynx habitat. Of the ten individuals identified, five were detected at stations with no attractant (blind sets), and nine, at the lured stations. Thirty-eight percent of blind set station's independent captures and 10 % of lured station's independent captures resulted in photographs unsuitable for correct individual identification. The total capture probability at lured stations was higher than that obtained at blind set stations. The estimates obtained with blind set cameras underestimated the number of lynxes compared to lured cameras. In our study, it appears that the use of lures increased the efficiency of trail camera captures and, therefore, the accuracy of capture–recapture analysis. The observed failure to detect known individuals at blind set camera stations may violate capture–recapture assumptions and bias abundance estimates.

Keywords *Lynx pardinus* · Iberian lynx · Camera trapping · Capture–recapture · Population estimates · Attractant lure

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Capture–recapture analysis of camera trap data is a conventional method to estimate the abundance of free-ranging wild felids (i.e., Karanth and Nichols 1998; Jackson et al. 2006; Garrote et al. 2011). These animals occur in low densities, which results in low detection rates during camera trap studies. Consequently, to meet capture–recapture assumptions (Otis et al. 1978) and increase the precision of abundance estimations, it may be important to increase detection probability during sampling occasions (Karanth and Nichols 2002). This could be done by strategically placing camera stations along probable travel routes with signs (tracks and/or scats) of the target species (Karanth and Nichols 2002; McCain and Childs 2008) or using attractant lures (Guil et al. 2010).

Few carnivore studies based on capture–recapture estimates use lures (Trolle and Kery 2003; Garrote et al. 2011). However, it has been shown that different types of attractants can lead to differences in the number of individuals detected and the rate at which they are detected within the photographic sampling sessions (Chamberlain et al. 1999; Howard et al. 2002; Guil et al. 2010). Using attractants at

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camera trap stations will increase the detection probabilities of individuals over unlured or blind camera stations. The increased probability of detection will increase the precision of estimates (Harmsen et al. 2010) and reduce the time necessary to detect all individuals in the study populations.

In our study, conducted within the monitoring program of the European Union's LIFE project "Conservation and reintroduction of the Iberian Lynx (*Lynx pardinus*) in Andalusia," (Simón et al. 2012), we compare the effectiveness of camera-trapping stations with and without attractant lures. The Iberian lynx was declared critically endangered in 2002 (IUCN 2002, 2007) when Guzmán et al. (2004) determined that only two small populations of the species remained. Over the last decade, camera trapping has been an important method for annual monitoring of the species' numbers and population trends (Gil-Sanchez et al. 2011). Therefore, it is also important to evaluate the efficiency of monitoring protocols to increase the efficiency and reliability and to reduce monitoring costs. We report the effectiveness of attractant lures as a tool for improving the efficiency of camera trapping in abundance estimations of this endangered species.

The study was conducted on a private estate within the known range of the Sierra Morena Iberian lynx population (southeast Spain; Simón et al. 2012). The area is managed for big game and has high densities of red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*), partially protected by the Parque Natural Sierra de Andujar. The area's altitude ranges between 200 and 1,500 m, and the vegetation is well preserved Mediterranean woodlands (*Quercus ilex*, *Quercus faginea*, and *Quercus suber*) and scrublands (*Quercus coccifera*, *Pistacia lentiscus*, *Arbutus unedo*, *Phillyrea angustifolia*, and *Myrtus communis*).

This estate is part of the long-term Iberian lynx conservation program, where intensive camera trapping has been performed annually over 8 years to closely monitor the individuals within the population (Gil-Sanchez et al. 2011). Data from 6 months of continuous camera trap sampling (June–November 2010) show that our specific study area was occupied by ten individual Iberian lynxes (four adult females, two adult males, two subadult females, and two subadult males) during the study period.

Two digital trail camera models: Leaf River Outdoor Products (Taylorsville, MS, USA) and Covert Scouting Cameras Inc. (Lewisburg, KY, USA) were used in the long-term monitoring program. Prior to the capture–recapture experiment, we evaluated the relative effectiveness of these camera models. One observer passed slowly 3 m in front of a bench where four cameras of each model were mounted. This was repeated 30 times with >1 min between passes to allow cameras to reset. In this blind set test (with no attractant), the Covert cameras, with a faster trigger speed, were successful in obtaining a photograph of sufficient quality in 85 % of trials (n=120). However, Leaf River cameras obtained suitable photographs in only 19 % of trials (n=120). Since the Leaf River cameras were slower and less dependable, we deployed them only at lured stations. We used the faster Covert cameras at the blind set camera stations.

Camera-trapping stations (lure station, n=6; blind station=5) were installed in a grid system. Blind sets stations and lure stations were installed alternatively spaced a minimum of 834 m to avoid a possible effect between stations. The sampling areas were calculated adding a buffer to the area defined by the outer trap polygon. The one-half mean maximum distance moved (one-half MMDM) were used to calculate the buffer width (Karanth and Nichols 1998). The total area covered was 2,283 ha. The area covered by blind set and lured stations was 1,663 and 1,955 ha, respectively. The difference in area covered between the two treatments is approximately one third of the Iberian lynx home ranges in the area (830 ha; Gil-Sanchez et al. 2011).

All cameras stations were located along lynx travel routes (Karanth and Nichols 1998; McCain and Childs 2008). Blind set cameras were installed 2–3 m perpendicular to the travel route to obtain a broadside photograph of the animal as it moved past. Live prey has been reported as the most efficient lure for sampling Iberian lynxes (Guil et al. 2010). The lured camera stations contained rock pigeons (*Columba livia*) in wire cages inaccessible by lynxes (Guil et al. 2010). Cages were approximately 50×50×50 cm and supplied with ample water and food each week. Lure stations were installed just off the edge of the travel route. Camera remained active 24 h/day and scheduled to take three pictures each time an animal was detected. The sampling period was 2 months, July–September 2009, which was sufficiently short to meet closed population assumptions (Larrucea et al. 2007; Garrote et al. 2011).

All lynxes photographed were individually identified through a comparison of distinguishing natural body spots (Garrote et al. 2011). Camera trap capture histories were developed for each lynx identified greater than a year old (Karanth and Nichols 1998). The sampling period was divided into eight 1-week capture periods; each of which was considered a separate trapping occasion. Capture history matrices were developed and analyzed separately for blind and lured camera stations. The capture history data were analyzed using the program CAPTURE (Rexstad and Burnham 1991) developed to implement closed population capture–recapture models. The program CAPTURE produces abundance estimates from models that differ in their assumptions about capture probability: individual heterogeneity (Mh), behavioral response (Mb), and temporal variation. To identify an adequate model for estimation, we used the goodness-of-fit test, between-model test, and the model selection algorithm provided in CAPTURE (Otis et al. 1978; Karanth and Nichols 1998; Wegge et al. 2004).

We obtained 41 lynx's independent captures (captures separated >1 h or different individuals) (n=313 photographs of lynxes) with 21 (n=51 photographs) obtained at blind stations and 20 (n=262 photographs) at lured stations. Thirty-eight percent (n=8) and 10 % (n=2) of independent captures at blind and lured stations, respectively, obtained photographs unsuitable for correct individual identification due to movement causing blurred images or insufficient portions of the animal in view. In total, all ten lynxes previously known to inhabit the area were identified. Five of these individuals were detected by the blind stations, and nine, at the lured stations.

The Homogeneity model Mo was selected by the program CAPTURE for both blind and lured stations; in addition, population size was calculated using the model Mh, which makes greater biological sense and hosts greater robustness against violating the assumption of capture heterogeneity (Otis et al. 1978; Karanth and Nichols 1998), and model Mb to test a possible lure effect in recapture probability. The population estimates obtained is presented in Table 1

The estimated probability of capturing a lynx at least once during the entire study period (P) is given by the ratio of the total number of animals captured to the estimated population size (Karanth and Nichols 1998). Considering the estimate of ten individuals as the closest to reality, the total capture probability for lured stations is P=0.9 (9/10), and for blind set stations, is P=0.5 (5/10). The total capture probability for lured stations is higher than that obtained for blind set stations throughout the study, and lured stations reached higher P values in fewer trapping occasions than blind set stations (Fig. 1).

The results obtained with the blind set stations data underestimated the number of lynxes identified, with regards the lured cameras. Since the density of cameras and the habitat characteristics were maintained constant for blind and lured camera stations (Henschel and Ray 2003), it appears that the increased effectiveness at lured camera stations is likely a result of the effect of the lure present at those stations. This may be related with the fact that lures

Table 1 Estimates of capture–recapture models (Mo, Mh, and Mb) for the camera-trapping data on Iberian lynx sampled with and without lure

Station	Model	Model selection criteria	Number	SE	$\widehat{p}$	$\widehat{c}$
Lure	Mo	1.00	9	0.73	0.34	–
Blind	Mo	1.00	5	0.88	0.25	–
Lure	Mb	0.66	9	0.73	0.34	1.13
Blind	Mb	0.57	5	0.22	0.45	1.17
Lure	Mh	0.88	10	2.66	0.18	–
Blind	Mh	0.94	7	1.89	0.17	–

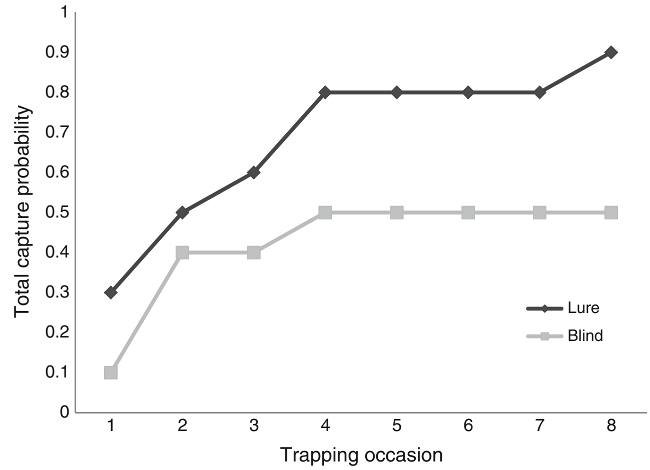

Fig. 1 Evolution of the total capture probabilities (individuals detected/estimated population) of Iberian lynxes in the eastern Sierra Morena Mountains, Andalusia, Spain, obtained during eight 1-week camera-trapping occasions at lured and blind camera stations

encouraged animals to remain stalled in front of the camera for enough time to minimize the problems of slow trigger speed, thus producing a quantity and quality of photographs adequate to correctly identify the individuals (Guil et al. 2010; Maffei et al. 2011; Gil-Sanchez et al. 2011). Despite the disadvantage of the Leaf River camera's poor detection rates in our field tests, photographs obtained at lured camera stations were superior in quality, which aided in individual identification. This is important because, in camera trap population estimation, there is a great percentage of individuals (40–55 %) that are detected only once (Silver et al. 2004; Dyllon and Kelly 2007; Silveira et al. 2009), thus failure to identify the individual in those cases would result in the loss of the only register for some individuals.

The treatment with higher initial capture probability ($\widehat{p}$) value varies depending on the model applied (Table 1), despite the fact that total capture probabilities for lured stations (0.9) were higher than those for blind set stations (0.5). It is possible that the estimates obtained from the blind set camera stations were biased by a camera station's failure to adequately sample its area of influence, therefore leaving a gap in the study area and potentially permitting the existence of individuals with a zero probabilities of being captured and violating a key capture–recapture assumption (Otis et al. 1978; Karanth and Nichols 1998).

A reduced recapture probability ($\widehat{c}$) relative to the initial capture probability ($\widehat{p}$) was found in the Mb estimate for lured stations, probably caused by a trap-shy response to no accessibility of the live lure. This must be considered in the case of extended surveys. Additionally, the use of live baits could result in logistical complications. Live prey was chosen as the attractant over other lures because it has been reported as the most efficient lure for sampling Iberian lynxes (Guil et al. 2010) and, therefore, was expected to produce a more marked effect in this study than other lure types. However, other attractants, such as lynx urine (Garrote et al. 2011), certain foods (Trolle and Kery 2003), or natural scent (latrine; Guil et al 2010) can be used to simplify the sampling effort.

Finally, lured stations reached higher *P* values in fewer trapping occasions than blind set stations (Fig. 1). This is important for a number of reasons. First, the use of attractants facilitates population estimates over shorter study periods, reducing project costs (White et al. 1982). This is important in the design of monitoring schemes constrained by time and financial resources. Second, the decrease in the sampling period will reduce the possibility of violating the closed population assumptions (Otis et al. 1978). Third, shorter sampling periods will also reduce other sources of variability commonly associated with long sampling periods, such as higher heterogeneity in the capture probability of individuals (Wegge et al. 2004).

In conclusion, our data strongly suggest that the use of attractant lures increases the effectiveness, accuracy, and efficiency of capture–recapture abundance estimates in the Iberian lynx. Similar analysis may be necessary for other research situations; however, the observed benefits from the presence of lures at camera trap stations may also be applicable other capture–recapture abundance estimates with other species.

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CAPITULO 3

Comparación entre el conteo de excrementos y el fototrampeo para evaluar la abundancia del lince ibérico (*Lynx pardinus*).

En revisión en European Journal of Wildlife Research:

Garrote G, Perez de Ayala R, Tellería JL. En revisión**.** A comparison of scat counts and camera trapping to assess Iberian lynx abundance.

Comparación entre el conteo de excrementos y el fototrampeo para evaluar abundancia del lince ibérico (*Lynx pardinus*).

Contar con métodos rigurosos y económicos es esencial para gestionar poblaciones de fauna salvaje, especialmente con aquellas especies que necesitan seguimiento continuado. En los últimos años, como resultado de los programas de conservación, el área de distribución y el número de ejemplares de las poblaciones de lince ibérico se han incrementado notablemente. Ante este escenario de expansión, el seguimiento de sus poblaciones mediante fototrampeo puede llegar a ser logística y económicamente inabarcable. Comprobamos si mediante el conteo de excrementos es posible predecir las densidades de lince ibérico determinadas mediante a fototrampeo, y evaluamos el costo económico de ambos métodos como una manera de proporcionar una evaluación comparativa de los dos enfoques de seguimiento de las poblaciones de lince ibérico. Encontramos una relación lineal significativa entre las abundancias obtenidas mediante ambas aproximaciones metodológicas (GLM $F_{1,7}$=45.81, P<0.001). La evaluación de la abundancia de lince ibérico mediante el conteo de excrementos fue seis veces más económica que su evaluación mediante fototrampeo. Nuestro estudio muestra que el conteo de excrementos es un método no invasivo económico que puede proporcionar evaluaciones fiables de la abundancia de lince ibérico. Sin embargo, para obtener resultados comparables, los muestreos deben llevarse a cabo entre áreas con condiciones lo más parecidas posibles y en la misma época del año. Ya que diferentes factores pueden afectar a la abundancia de los excrementos, se sugiere evaluar el efecto potencial de estos factores sobre las estimas de cara a perfeccionar el método.

A comparison of scat counts and camera trapping to assess Iberian lynx abundance

Rigorous cost-effective census methods are an essential part of managing wild animal populations, particularly if the involved species require continuous monitoring. In recent years, the range and size of the Iberian lynx (*Lynx pardinus*) population has increased notably as a result of conservation programs. Given this expansive scenario, monitoring Iberian lynx using camera-traps may become logistically and financially unfeasible. Here we test whether or not scat counts are as efficient as camera-trapping in predicting lynx densities, and compare the cost of these two approaches to lynx monitoring. We found a significant positive linear relationship between these two methods of assessing Iberian lynx abundance. Lynx abundance assessment by scat counting was six times less expensive than camera-trapping; there was no significant effect of the two study areas on the observed patterns (GLM $F_{1,7}$=45.81, P<0.001). Our study shows that scat counting is a non-invasive cost-effective method that can provide reliable assessments of Iberian lynx abundance. However, if comparisons are to be made, censuses should be carried out (a) under as nearly identical conditions as possible and (b) in the same season. A number of different factors affect scat abundance and in order to improve counts it would be of great interest to evaluate the potential effect of the factors that cause scat estimates to vary.

A COMPARISON OF SCAT COUNTS AND CAMERA-TRAPPING AS MEANS OF ASSESSING IBERIAN LYNX ABUNDANCE

Introduction

Rigorous cost-effective census methods are an essential part of managing wild animal populations, particularly if the species involved require continuous monitoring (Roberts 2011). In this context, comparisons between census methods are useful for detecting the most efficient monitoring strategies. Camera-trapping was first used by Karanth (1995) to assess the size of an endangered tiger population and since then it has proven to be an accurate method for counting certain species of carnivores (Balme et al. 2009; Silver et al. 2004; Trolle & Kery 2003). However, if forming part of large-scale monitoring programs, camera-trapping is expensive since a large number of devices and field/laboratory hours are required. This suggests that there is a need to test the potential usefulness of alternative, more cost-effective methods that can be used routinely in monitoring schemes.

Scat counts have been described as suitable, cheap and quick methods of assessing carnivore distributions and abundances (Palomares et al. 2002; Cossios et al. 2007; Perez et al. 2006; Mondol et al. 2009; Ruell et al. 2009). Nevertheless, they have certain limitations since sympatric carnivores often have similar scats (Farrell et al. 2000). To circumvent this problem, scats can be identified using genetic techniques (Mondol et al. 2013), a process that, obviously, increases costs. Since the efficient use of resources is of paramount importance, this shortcoming in scat identification could in some cases rule out the use of this otherwise valuable method in large-scale population monitoring programs (Lucherini et al. 2009).

The Iberian lynx (*Lynx pardinus*), one of the world's most endangered vertebrate species (Nowell and Jackson 1996), is monitored annually by camera-trapping in Doñana and Sierra Morena, the two disjoint areas of its current range in Spain (Simon et al. 2012; Garrote et al. 2011). Due to a series of proactive conservation programs, the range and size of the Iberian lynx population in the larger of the two areas (Sierra Morena) increased from 11,900 ha and 59 individuals in 2002 to 26,000 ha and 179 individuals in 2010 (Simón et al. 2012). Under this expansive scenario, monitoring Iberian lynxes using camera-traps is not logistically or financially feasible and so it is vital that the cost-effectiveness of other monitoring methods be evaluated. Scat counts are a suitable way of assessing the spatio-temporal patterns of Iberian lynx abundance but do imply an additional cost given the need for the genetic testing of lynx scats due to their similarity to wildcat (*Felis sylvestris*) and red fox (*Vulpes vulpes*) scats (Palomares et al. 2002).

In this study we assess the usefulness of scat counts as estimates of Iberian lynx abundance and their potential as cost-effective surrogates for camera-trapping. Thus, we (a) tested to see whether or not scat counts are able to predict the lynx densities determined by camera-trapping and (b) compared the economic cost of these two approaches.

Methods

Study area

The study areas are located in the eastern Sierra Morena (SE Spain) and Doñana (SW Spain). The Sierra Morena is an upland area with altitudes ranging between 200 and 1,500 m that is covered by Mediterranean forests (*Quercus ilex, Q. faginea* and *Q. suber*) and scrublands (*Q. coccifera, Pistacia lentiscus, Arbutus unedo, Phillyrea angustifolia* and *Myrtus communis*). Doñana, on the other hand, is a flat coastal area covered by Mediterranean scrub (*Pistacia lentiscus* and *Juniperus* sps.), *Eucalyptus* and pine plantations, wood pastures, seasonally flooded marshes, dunes and cultivated land. We selected ten 5x5 km UTM grid squares (five in Doñana and five in Andújar) in 2001 to assess simultaneously Iberian lynx abundance using both camera-trapping and scat counts.

Camera-trapping.

We used 212 35-mm cameras with data registers and automatic flashes. The cameras were modified to allow activation via an external 25×25 cm pressure plate, positioned at a distance of 170 cm, that was triggered when stepped on by an animal (Garrote et al. 2011). Urine from captive Iberian lynxes placed on an inert support 50 cm above the ground and adjacent to the pressure plate was used as a lure. This attractant was replaced every 3–6 days. The distance between the camera traps was 400–800 m. All photographed individuals were identified by comparing the spots on their coat (Garrote et al. 2011). The cameras were active for two months, the time required to stabilize the accumulation curve for individual lynxes (Guzman et al. 2004). We used photo-trapping data from the annual national Iberian lynx survey (Guzman et al. 2004; Garrote et al. 2011), which covers 85% of the area potentially used by the Iberian lynx (both in Doñana and Andújar-Cardeña). The total number of stations in each grid square ranged from 12 to 30, depending on the amount of potential Iberian lynx habitat in each square. We calculated Iberian lynx density (minimum number of individuals/100 ha) in each square from the data provided by the camera stations (including cameras located both inside and outside the squares). The contribution of every individual to a given square was determined in terms of the number of times that its presence was detected in the grid square (the number of different photo-events; method adapted from Palomares et al. 2001), that is, if an individual appeared in five out of a total of 10 photo-captures in a given grid square, then this animal was determined to have contributed 50% of the density of that grid square.

Scat surveys

Sampling was conducted in February–April 2001. Scat censuses were carried out along 14–18-km itineraries in each 5x5-km grid square. The search effort was focused on trails, tracks and paths in each square (Sarmento et al 2009). All lynx-like scats found during the censuses were collected for molecular analysis. Scats were collected meticulously to prevent genetic contamination and were analyzed with molecular techniques that identify scats unambiguously to species level (Palomares et al. 2002). Data were genotyped by the Doñana Biological Station (CSIC) and an abundance index expressed as 'scat/km' was obtained for each grid square. Additionally, one grid square was selected to study the potential variations in scat/lynx abundance during the year. In this square we searched for scats in all four seasons of the year.

Statistical analysis

A simple regression analysis between the number of scats/km and the lynx density (minimum number of individuals/100 ha) obtained for each UTM square was conducted to assess the relationship between these two variables. We also included the effect of the study area (Doñana vs. Sierra Morena) in an ANCOVA analysis in order to detect potential inter-site differences in the way in which scat counts were transformed into lynx densities. All analyses were carried out using the GLM module in Statistica 7.0 (StatSoft Inc, Tulsa, Oklahoma).

Cost

We assigned a similar cost for field sampling per day per person to both camera-trapping and scat counting (70.17 € per hour; 7.5 hours of field sampling per day; rates established according to the official rates of the Spanish Administration; B.O.E 2013 XVII: *Convenio colectivo nacional de empresas de ingeniería y oficinas de estudios técnicos*. Nº 256. Pg. 86,811–86,838). To assess the cost of field sampling, we considered a mean petrol consumption of 9.5 l/100km and a mean price of 1.35 €/litre (average price in Spain in April 2013; *Ministerio de Industria, Comercio y Turismo*. www.minetur.gob.es), which gave an average cost of 0.13 €/km. We calculated 80 km per day, but for camera trapping we increased this figure by 25 km per day (to account for periodical revision of the cameras). We also included a depreciation cost of 38.60 € per day for a standard 4x4 vehicle (www.bujarkay.com). We estimated a similar length of time for both methods for writing the final report once the data had been processed and analyzed.

In the case of camera-trapping, we observed that one person could check 25–30 cameras per day (7.5 hours). In addition, two days were needed to install the cameras and eight weekly revisions were carried out (the last of which was to retire the cameras). We spent five days identifying the photographed lynxes and creating the database of photographs for counting the animals. The cameras cost around 250 € (Scotguard SG 580, Moultrie M990). In our experience, each camera has a mean lifespan of around five years if we take damage and robbery into account. We thus divided by five the total cost of the cameras used in this study.

Finally, we spent around 2 € per camera on the eight AA batteries used during the study.

In the case of the scat counts, one person per day was employed to sample each 5x5 km grid square. Detected scats were analyzed by the Doñana Biological Station/Spanish National Research Council at a cost of 30 € per scat. Other material included bags (5 €/ 500 units), 2–5 mm diameter silica gel beads (6.10 €/kg) and plastic pots (49.95 €/100 units). We devoted one day to the sending of the scats to be analyzed and to setting up the database.

Table 1. Economic costs of camera trapping and scat counting of Iberian lynxes on the today range of the species.

	Scat counting					Camera trapping			
	UD	€	Total €	$		UD	€	Total €	$
Days of work	11	70.17	771.87	1003.43	Days of work	120	70.17	8420.4	10946.52
Car renting	10	38.6	386	501.80	Car renting	80	38.6	3088	4014.4
Petrol	10	10.26	102.6	133.38	Petrol	80	13.47	1077.6	1400.88
Genetic analyses	91	30	2730	3549.00	Cameras / 5 years	212	250	10600	13780
Bags. etc.			61.5	14.95	Batteries	212	2	424	551.2
Mail	1	5.1	5.1	6.63					
TOTAL			4068.52	5209.19	TOTAL			23610	30693

*US dollar change 19/04/2013 (1€/1.30 $)

Results

Camera-trapping identified a total of 45 different lynxes (29 in Sierra Morena and 16 in Doñana), at a density of 1–11 different individuals per grid square. The mean lynx density per square was 0.45 ind./100 ha (min-max: 0.027–0.89). In all, 91 scats were collected during the scat counts, of which 82 were determined by molecular methods to be Iberian lynx scats. The mean abundance was 0.54 scats/km (min-max: 0.066–1.12). The analysis of annual changes in abundance indices showed that the number of droppings detected varied according to the season. Most scats were detected in the autumn (9.71 ex./ha), followed by summer (6.35 ex./ha), winter (2.16 ex./ha) and spring (2 ex./ha). We found a significant positive linear relationship between the two methodological approaches in the assessment of the Iberian lynx abundance; there was no significant effect of the study area on the observed patterns (GLM lynx density $F_{1,7}$=45.81, P<0.001, study area $F_{1,7}$=1.74, P=0.228; Fig 1). According to the cost assessment, scat counts were more effective than camera trapping in all senses (Table 1): lynx abundance assessment using scat counts was six times less expensive than camera-trapping.

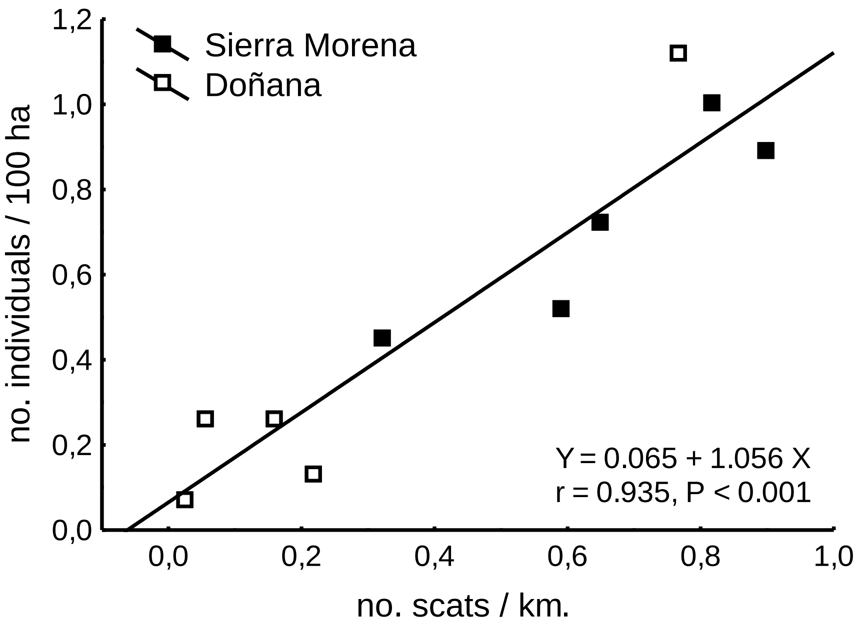

Fig.-1. Relationships between scat count indexes and Iberian lynx densities in Sierra Morena and Doñana.

Discussion

Our results show that scat counts are a non-invasive cost-effective method that can provide reliable assessments of Iberian lynx abundance. More explicitly, they suggest that this method can provide a reliable index of the spatial distribution of lynx density that is comparable to the results obtained by the more expensive camera traps. However, it is important to stress that the application of this methodological approach to Iberian lynx monitoring must be subject to certain criteria.

First of all, it should be emphasized that if any comparisons are to be made censuses should be carried out under as similar conditions as possible (Seber 1982). This means that scats counts should only be used for monitoring the spatial and temporal distribution of Iberian lynx if the potential effect of a number of methodological constraints are considered. For example, it is important to realize that defecation rates usually differ between areas and seasons as a result of variations in diet (Andelt & Andelt 1984). This will probably only have a minor effect on lynx monitoring since its main prey item throughout the whole year are wild rabbits (Gil-Sanchez et al. 2006). Nevertheless, other seasonal changes such as the effects of the weather (Cavallini & Santini 1996; Andelt & Andelt 1998) and the presence of coprophagous beetles (Norris & Michalsky 2010), more abundant in spring and summer (Palomares et al. 2002), may affect scat survival and detectability. The effect of all these environmental correlates on scat availability, which varies between years, seasons and areas (Cavallini & Santini 1996; Norris & Michalsky 2010; Brinks et al. 2005; Parry et al. 2006), needs to be investigated before any extensive application of scat counts to lynx monitoring be considered. It would also be worth evaluating whether or not controlling for some of these effects improves scat counts. For instance, the effect of rates of scat decay under different circumstances (weather, vegetation cover, etc.) or the most suitable time interval between counts on transects along which scats have been previously collected (e.g. Smart et al., 2004) could be explored.

Secondly, only scat counts carried out in comparable annual periods will be useful for monitoring inter-annual changes in lynx populations since scat abundances reflect seasonal changes in abundance (e.g. the summer-autumn recruitment of young individuals after breeding) as in other carnivore species (Cavallini & Santini 1996; Genovesi et al. 1996). Thus, despite the usefulness of scat counts and DNA identification for detecting lynx presence (Guzmán et al. 2004; Alda et al. 2008) and lynx dispersion and/or colonization of new areas, and for generating data on other aspects of lynx ecology (Fernandez et al. 2006), it is still essential to define the annual period in which inter-annual monitoring is to be carried out.

Finally, abundance indexes are usually transformed into a measure of absolute density if a reliable conversion factor is available (Seber 1982). In this way, low-cost monitoring counts could be used to give the same absolute densities as provided by high-cost methodological approaches if both counts are applied simultaneously to the same populations during the same annual period. This is the aim of most comparative evaluations of counting methods (e.g. Barnes 2001; Silveira et al. 2003; Harrington et al. 2007; Acevedo et al. 2010). Thus, the equation in Figure 1 could be used to predict lynx densities (or population size) on the basis of scat counts. However, the soundness of such correlational evidence still needs to be fully validated by applying the model to independent data generated by camera-trapping or other reliable approaches to the measurement of population sizes and/or densities.

The results given in this paper strongly suggest that scat counts are a promising alternative for calculating Iberian lynx abundance in large areas where, due to logistical or cost constraints, it is too expensive to employ camera traps. If the Iberian lynx continues to expand, it is possible that this indirect method of assessing lynx abundance will become a highly suitable way of monitoring its populations. It will be of particular use if annual scat surveys conducted in lynx-occupied regions are periodically complemented by simultaneous intensive camera-trapping to assess the actual size of monitored populations since factors affecting scat abundance (e.g. weather, vegetation cover, habitat, coprophagous insects, etc.) may vary between years or areas (Norris & Michalsky 2010; Parry et al. 2006). It is, therefore, imperative to understand the factors that cause such estimates to vary and exactly how estimates vary in response (Harrington et al. 2007). This double approach could be used to test periodically the ability of scat counts to predict lynx densities and infer the size of lynx populations.

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CAPITULO 4

Evaluación de las tasas y causas de mortalidad de un felino en peligro crítico en toda su área de distribución.

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Evaluación de las tasas y causas de mortalidad de un felino en peligro crítico en toda su área de distribución.

La conservación de especies amenazadas requiere el uso de información adecuada, y el conocimiento de las tasas y causas de mortalidad de las especies es uno de los aspectos más importantes a considerar. Los programas de conservación del lince ibérico (*Lynx pardinus)* llevados a cabo en los últimos años han sido desarrollados en base a datos de mortalidad obtenidos hace 30 años en la población de Doñana. Se hace necesario por tanto una actualización de las tasas y causas de mortalidad en las dos poblaciones existentes (Doñana y Sierra Morena). Para ello, usamos información de radioseguimiento de 78 linces ibéricos procedentes de ambas poblaciones (39 de Sierra Morena y 39 de Doñana). Cada ejemplar muerto fue evaluado para identificar la causa de la muerte, y se obtuvieron las Tasas Anuales de Mortalidad (TAM) mediante el estimador de la función de incidencia acumulada medido en forma no paramétrica. En conjunto se estimó una TAM de 0.16±0.05 (0.19±0.09 en Sierra Morena y 0.12±0.07 en Doñana). Las enfermedades fueron la principal causa de mortalidad para la población en conjunto y para la población de Doñana. La caza ilegal fue la principal causa de mortalidad en Sierra Morena. Nuestros resultados sugieren que la mejor estrategia para la conservación de esta especie es de concentrar las acciones en la disminución de los efectos mortales de las enfermedades y la caza furtiva. Dada la posible existencia de inmunosupresión debida a un alto grado de consanguinidad en la población de Doñana, se recomienda el manejo genético destinado a aumentar la diversidad genética de esta población.

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ORIGINAL PAPER

Evaluating mortality rates and causalities in a critically endangered felid across its whole distribution range

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Abstract The conservation of endangered species requires accurate data, and knowledge of cause-specific mortality rates is one of the most important issues. In recent years, conservation programs for the critically endangered Iberian lynx *Lynx pardinus* have been developed on the basis of mortality data derived 30 years ago from the small Doñana population. Thus, there is an urgent need for an update of mortality rates and causes in both populations (Sierra Morena and Doñana). Here we use radio-tracking information from the whole range of the Iberian lynx to quantify mortality rates and identify their causes. Between 2006 and 2011, we radio-tagged 78 Iberian lynxes from its two remaining populations (39 from Sierra Morena and 39 from Doñana). Mortality events were evaluated to identify causes, and cause-specific annual mortality rates (AMR) were obtained using the nonparametric cumulative incidence function estimator. Overall, AMR was estimated at 0.16±0.05 (0.19±0.09 in Sierra Morena and 0.12±0.07 in Doñana). Disease was the main cause of mortality both for the whole population and the Doñana population. Poaching was the main cause of mortality in Sierra Morena. Our results suggest that the best strategy for conserving this species is to focus action on decreasing the fatal effect of disease and poaching. Given the possible existence of an underlying inbreeding-mediated immunosuppression, genetic management aimed at increasing the genetic diversity of this population is also recommended.

Keywords Iberian lynx · Mortality rate · Survival · Diseases · Poaching

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Introduction

A precise knowledge of survival and cause-specific mortality rates is critical for undertaking effective conservation measures aimed at preserving endangered species (Heisey and Fuller 1985). Besides their use in assessing population status and in providing high-quality information for predicting the evolution of populations, knowledge of survival and cause-specific mortality rates is essential for developing efficient means of overcoming the factors that hamper the conservation of animal populations. In the case of wild populations, the main obstacle lies in the difficulty in obtaining reliable cause-specific mortality data (Eberhardt 1985). Given that the detection probabilities for different causes of mortality vary (Bischof et al. 2009; Liberg et al. 2012), the most reliable method of quantifying mortality rates in mammal populations is to record their fates over time using radio-tracking (Heisey and Fuller 1985). Survival and cause-specific mortality studies based on radio-tracking data can provide valuable results for the conservation of endangered carnivores (Goodrich et al. 2008; Maran et al. 2009; Persson et al. 2009).

With only about 400 remaining individuals (Simón et al. 2013), the Iberian lynx (*Lynx pardinus*) continues to be the most endangered cat species in the world (International Union

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for Conservation of Nature 2012). Its populations suffered a dramatic decrease during the twentieth century (Gil-Sánchez and McCain 2011), and by 2002, only 93 individuals were estimated to remain in two isolated populations in Andalusia (S Spain): eastern Sierra Morena and the Doñana area (Simón et al. 2012). The main causes thought to have led to this critical situation were (1) an increase in nonnatural mortality, (2) a decrease in wild rabbit (*Oryctolagus cuniculus*) (the Iberian lynx's staple prey item) populations due to introduced diseases, and (3) habitat destruction (Rodríguez and Delibes 2004). Since 2002, three consecutive LIFE-nature projects (European Union-funded projects for environmental and nature conservation) have been devoted to the conservation of this lynx in Andalusia (hereafter ILLP). The conservation actions implemented by the ILLP include an increase in the carrying capacity of occupied habitats (by enhancing wild rabbit populations) and a reduction in direct threats to Iberian lynx populations (aimed mainly at decreasing known causes of mortality) (see Simón et al. 2013 for details). One of the main objectives was to reverse the species' decline by mitigating the most significant detected causes of mortality (Simón et al. 2012). However, this conservation work was largely conducted on the basis of studies from the previous century (from 1950 to 1989). The only study of cause-specific mortality in the Iberian lynx using radio-tracking data was conducted in the Doñana population between 1983 and 1989 (Ferreras et al. 1992), the remaining information being based on (1) anecdotal findings (González-Oreja 1998; García-Perea 2000; López-Parra et al. 2012), (2) surveys (Rodríguez and Delibes 2004), or (3) data from a small segment of the population (Ferreras et al. 2004; Palomares et al. 2012). Between 2002 and 2011, the Iberian lynx population grew from 93 to 326 individuals (Simón et al. 2012); as well, two new population nuclei were created using reintroductions (Simón et al. 2012), and genetic management was attempted (Ruiz et al. 2009; Simón et al. 2012). Although actions focused on decreasing mortality seem to have helped reverse the decline in the species' populations (López-Parra et al. 2012; Simón et al. 2013), the relative importance of each action is still hard to assess due in part to a lack of updated and comprehensive cause-specific mortality data. Under this scenario, a detailed study of the recent cause-specific mortality rates in the Iberian lynx population is essential if future measures aimed at decreasing mortality are to be successfully and efficiently implemented. We hypothesized that (1) cause-specific mortality rates have changed in the last 20 years and (2) that the relative importance of the different causes of mortality are different between the two Iberian lynx populations. Hence, the goal of this study was to determine the current cause-specific mortality rates in wild Iberian lynx populations throughout the whole of its range in order to evaluate and improve conservation measures.

Material and methods

Study area

The Iberian lynx ranges over 70,300 ha of the southern Iberian Peninsula (Simón et al. 2012), mostly inside the Andújar and Cardeña y Montoro Natural Parks (both in eastern Sierra Morena) and the Doñana Natural Space (formerly the Doñana National Park plus the Doñana Natural Park). In Sierra Morena, a low rocky mountain chain derived from a granite batholith and mostly covered by Mediterranean scrub. The main land use is big-game hunting driven by the high densities of red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*). The Doñana is a sandy coastal area where patches of well-preserved Mediterranean scrub mix with umbrella pine *Pinus pinea* plantations, marshes, and cropland. Land use in Doñana in the areas inhabited by the Iberian lynx generally consists of rabbit hunting and other recreational activities.

Iberian lynx tagging

Between 6 July 2006 and 31 December 2011, we radio-tagged 78 Iberian lynxes (39 from Sierra Morena and 39 from Doñana) as part of routine monitoring work for the ILLP (see Simón et al. 2013); in all, data from 57,168 transmitter-days were generated. All individuals were trapped using double-entrance box traps (see López et al. 2009). Once captured, they were transported in stainless-steel transport-compression cages to the nearest (from 1 to 30 km) Iberian lynx clinic (Simón et al. 2013). All individuals were anesthetized using a mix of ketamine–medetomidine or ketamine–dexmedetomidine; a supplementation with isofluorane inhalatory anesthesia was performed if needed (Martínez et al. 2007). Lynxes were individually identified on the basis of the patterns of their spots, and their age (in years) was recorded by comparisons with photos of cubs from previous years (see Garrote et al. 2011; López-Parra et al. 2012). Anesthetized Iberian lynxes were tagged with VHF (Wagener, Köln, Germany; n=63) or VHF-GPS-GSM (Televilt/TVP positioning AB, Lindesberg, Sweden; n=5; Microsensory, Fernán Núñez, Spain; n=10) collars. Collars weighed 220–300 g. Finally, a complete routine health evaluation was performed. After handling, all individuals were safely released at the place of capture.

Monitoring and carcass detection

All tagged individuals were located between 3 and 7 days a week; two to six additional locations per day were recorded of individuals tagged with VHF-GPS-GSM collars. Death events were identified by the mortality detection system on the collars, which activate automatically after 6 h of inactivity. The dead animal was then transported immediately to the official wildlife forensic laboratory of the Andalusian Regional Government's Department of Environment (Málaga, Spain). When the signal of one radio-tagged individual could not be found following the routine methods by land (see Simón et al. 2013), a careful search by plane or helicopter was conducted. If even so the signal could not be detected after 7 days, a failure of the collar or a poaching event (illegal killing followed by the destruction of the collar) was considered. To differentiate between them, we used routine ILLP camera-trapping monitoring to detect if the individual remained in the population, as based on the unambiguously distinctive individual pattern of coat spots (see Garrote et al. 2011; Simón et al. 2013). If camera-trapping failed capturing a lost individual during 6 months after the vanishing of the signal, the event was attributed to poaching. In such a case, the date of death was estimated as the mean period between the last triangulation and the first day we failed finding the signal (1–3 days after the last triangulation).

Identification of causes of death

We performed a necropsy on all the 24 radio-tagged Iberian lynxes found dead in the field. Necropsies were carried out following a specially designed protocol for the species (see Martínez et al. 2009). We determined five main causes of mortality: disease, fight, roadkill, poaching, and unknown. Deaths due to diseases were determined on the basis of molecular analyses (see Meli et al. 2009 for further details), macroscopic findings, microbiology, and histopathology (see Jiménez et al. 2009). Fights and roadkills were determined by the in situ postmortem inspection, the macroscopic findings, and the absence of any sign of disease or toxicology. Poaching events were identified on the basis of the in situ postmortem inspection, the routine x-ray studies (searching for ammunition), the toxicology analyses (cases of poisoning), and the absence of any sign of disease of other trauma. When all the analyses failed to detect the cause of death, lynxes were included in the “unknown” group.

Statistical analysis

On the basis of the data gathered, causes of death could be grouped into three more general classes: natural causes (disease or fight), anthropogenic causes (roadkill or poaching), or unknown causes. To explore annual mortality rates (AMR), we used the nonparametric cumulative incidence function estimator (NPCIFE) for left-truncated survival records, which offers a good estimator of the magnitude of several mortality causes and allows the relative impact of covariates to be assessed (Heisey and Patterson 2006). The AMR is thus expressed as the probability that an individual will die due to a given type of mortality event in any given year. We calculated the cause-specific AMR for the entire Iberian lynx population, as well as for the Sierra Morena and Doñana independently. In addition, mortality was divided into two separate age groups, namely subadults (6 months–2 years) and adults (>2 years). Given that subadults are known to disperse (Ferreras et al. 2004), the AMR was expected to be higher in subadults than in adults (see also Ferreras et al. 1992). Individuals of less than 6 months of age could not be fitted with a radio collar given their small size. NPCIFE indexes were calculated using wild1 package (Sargeant 2011) of R 2.14.2 software (http://www.r-project.org). Differences in the AMR between populations, age groups, origin (natural or anthropogenic), and period of time (1980s or today) were explored using Z tests using a liberal p value of 0.15 because of our small sample size (see Goodrich et al. 2008).

Results

Detected causes of mortality

A total of 26 death events (15 in Sierra Morena and 11 in Doñana; 33.3 % of the sample) were recorded in the sample during the study period, including the 24 carcasses plus two vanished individuals that were added to the poaching group. Twenty-two carcasses were found fresh (6–72 h after death), while two others were found at least 1 month after death (due to failures in the mortality detection system). The cause of death could be determined in 19 out of the 22 fresh carcasses (86.4 %) and in none of the two old ones. The most common cause of death in our dataset was infectious diseases, which accounted for as much as 38.5 % of all recorded mortalities (Table 1). The necropsies revealed two cases of tuberculosis, two of pasteurellosis, two of clostridiosis, one of feline leukemia virus infection, one of feline parvovirus infection, one of leptospirosis, and one of opportunistic bacterial overgrowth. This cause of death was particularly high in the Doñana population (63.6 %). The age of the animals that died of disease ranged between 2 and 11 years old. Poaching was the second most common cause of death (23.1 %; two were illegally box-trapped, one poisoned, and one caught in a leg-hold trap) and was more relevant in Sierra Morena (33.3 %) than in Doñana (9.1 %). Three lynxes died as a result of intra- or interspecific fights (carnivore bites were the proximate cause of death) and, finally, two due to car accidents (Table 1). The cause of death could not be accurately determined in five cases (21 % of the total).

AMR in the Iberian lynx population as a whole

The AMR of the Iberian lynx population as a whole was 0.16± 0.06 (mean±SE). The most important cause of AMR was

Table 1 Number and percentage (between brackets) of causalities grouped by causes of death in the radio-tagged sample of the Iberian lynx population recorded during the study period (2006–2011)

Cause	Total Iberian lynx			Sierra Morena			Doñana		
	Subadult	Adult	Total	Subadult	Adult	Total	Subadult	Adult	Total
Infectious disease	1 (14.3)	9 (47.4)	10 (38.5)		3 (33.3)	3 (20)	1 (100)	6 (60)	7 (63.6)
Fight	2 (28.6)	1 (5.3)	3 (11.5)	2 (33.3)		2 (13.3)		1 (10)	1 (9.1)
Roadkill		2 (10.5)	2 (7.7)		1 (11.1)	1 (6.7)		1 (10)	1 (9.1)
Poaching	2 (28.6)	4 (21.1)	6 (23.1)	2 (33.3)	3 (33.3)	5 (33.3)		1 (10)	1 (9.1)
Unknown	2 (28.6)	3 (15.8)	5 (19.2)	2 (33.3)	2 (22.2)	4 (26.7)		1 (10)	1 (9.1)
Total	7	19	26	6	9	15	1	10	11

diseases, followed by poaching, fight, and roadkills (Table 2). Significant differences in AMR were not found between subadults and adults (Z=1.3; p=0.30) nor between natural and anthropogenic causes (Z=0.7; p=0.48).

AMR in the Sierra Morena population

The overall AMR in Sierra Morena was 0.19±0.09. Poaching was the main cause of mortality in this population (Table 2).

Table 2 Cause-specific annual mortality rate (AMR) and the 95 % confidence interval (CI 95) in the Iberian lynx populations in the period 2006–2011. Data from subadults (<2 years) and adults (>2 years) are presented separately (the same individual may contribute to both subadults and adults during the study period)

Cause	AMR	CI 95	AMR	CI 95	AMR	CI 95
Iberian lynx population						
	Total (N=78)		Subadults (N=33)		Adults (N=63)	
Disease	0.06	0.02–0.09	0.04	0.00–0.12	0.06	0.02–0.10
Fight	0.02	0.00–0.04	0.06	0.00–0.15	0.00	0.00–0.02
Total natural	0.08	0.04–0.11	0.10	0.00–0.21	0.07	0.03–0.11
Poaching	0.03	0.00–0.06	0.06	0.00–0.15	0.03	0.00–0.06
Car	0.01	0.00–0.03	0.00	0.00	0.01	0.00–0.04
Total antropic	0.05	0.02–0.08	0.06	0.00–0.15	0.04	0.01–0.08
Unknown	0.03	0.04–0.06	0.06	0.00–0.15	0.02	0.00–0.05
Total	0.15	0.10–0.21	0.23	0.08–0.37	0.14	0.08–0.02
Sierra Morena						
	Total (N=39)		Subadults (N=17)		Adults (N=27)	
Disease	0.04	0.00–0.08	0.00	0.00	0.05	0.00–0.11
Fight	0.03	0.00–0.06	0.09	0.00–0.20	0.00	0.00
Total natural	0.06	0.01–0.12	0.09	0.00–0.20	0.05	0.00–0.11
Poaching	0.06	0.01–0.12	0.08	0.00–0.19	0.05	0.00–0.11
Car	0.01	0.00–0.04	0.00	0.00	0.02	0.00–0.05
Total antropic	0.08	0.02–0.13	0.08	0.00–0.19	0.07	0.00–0.14
Unknown	0.05	0.00–0.10	0.08	0.00–0.19	0.04	0.00–0.09
Total	0.19	0.10–0.28	0.25	0.08–0.43	0.16	0.07–0.26
Doñana						
	Total (N=39)		Subadults (N=16)		Adults (N=36)	
Disease	0.07	0.02–0.13	0.11	0.00–0.32	0.07	0.02–0.13
Fight	0.01	0.00–0.04	0.00	0.00	0.01	0.00–0.04
Total natural	0.09	0.03–0.14	0.11	0.00–0.32	0.09	0.03–0.15
Poaching	0.01	0.00–0.03	0.00	0.00	0.01	0.00–0.04
Car	0.01	0.00–0.04	0.00	0.00	0.01	0.00–0.04
Total antropic	0.02	0.00–0.06	0.00	0.00	0.03	0.00–0.06
Unknown	0.01	0.00–0.04	0.00	0.00	0.01	0.00–0.04
Total	0.12	0.05–0.19	0.11	0.00–0.32	0.13	0.05–0.20

The annual rates of anthropogenic and natural mortality were similar (Table 2), and no significant differences were found between them (Z=0.2; p=0.81). Similarly, the AMR of subadults and adults did not significantly differ in this population (Z=0.7; p=0.47).

AMR in the Doñana population

The overall AMR in the Doñana Iberian lynx population was 0.12±0.07 (Table 2). No significant differences were found between the annual rate of anthropogenic mortality and that of natural mortality (Z=1.2; p=0.22) nor between those of subadults and adults (Z=0.2; p=0.86).

Comparing the AMR between populations and periods of time

No significant differences in overall AMR (Z=0.8; p=0.41), in AMR of subadults (Z=1.1; p=0.28), in AMR of adults (Z=0.4; p=0.70), in AMR due to natural causes (Z=0.4; p=0.68), or in AMR due to anthropogenic causes (Z=1.1; p=0.28) were found between Sierra Morena and Doñana. The AMR decreased significantly in Doñana between 1983 and 1989 (Ferreras et al. 1992) and 2006–2011 (Z=2.4; p=0.02; Table 3). The only cause-specific AMR to significantly differ between periods was for that of poaching (Table 3). Finally, the AMR recorded in Sierra Morena in our study was significantly lower than that recorded in Doñana in 1983–1989 (Z=1.6; p=0.10; Table 3).

Discussion

This study represents the first cause-specific mortality analysis performed over the whole of the range of the Iberian lynx. Interestingly, disease was the main recorded cause of mortality during the study period and was especially important in the Doñana population. During the past decade, infectious diseases have been recognized as one of the most important threats affecting Iberian lynx populations (Millán et al. 2009; Meli et al. 2009). Different agents have been shown to have the potential to provoke mortality in the species (Aranaz et al. 2004; Meli et al. 2009, 2010). Indeed, an FeLV outbreak affected several individuals in Doñana during the study period (López et al. 2009), although only one affected individual had been tagged as part of this study. The relevance of disease as a cause of mortality revealed by our study contrasts with previous data from this species (Ferreras et al. 1992, 2004) and from other carnivore species (Farias et al. 2005; Andrén et al. 2006; Goodrich et al. 2008). Overall, poaching is the second most important cause of mortality but is the most important factor in Sierra Morena. This difference may be caused by a more intensive hunting activity in Sierra Morena than in Doñana. Four Iberian lynxes were killed using nonselective methods (leg-hold traps and box traps). Furthermore, two of the six fatalities attributed to poaching were probably deliberate responses by farmers to depredation by lynx on livestock (see Garrote et al. 2013). Mortality due to fights totaled three events in our study period. Unfortunately, only one of the three cases could be attributed with a degree of confidence to an intraspecific fight. In the other two cases, hunting dogs could have killed the lynx, and so these deaths should be added to the poaching group. Both intra- and interspecific mortality events have also been reported in other lynx species (Fuller et al. 1993; Andrén et al. 2006; Mattisson et al. 2013). Finally, although roadkills are usually highlighted in the mass media as one of the main threats to the Iberian lynx, our results show that they had the least impact of all causes of mortality on the Iberian lynx population during the study period.

The AMR recorded in Sierra Morena in our study is lower than the figures from the Doñana during the 1980s. Human activities are the main cause of mortality in Sierra Morena, as has been seen in other wild felid populations (Jedrzejewski et al. 1996; Goodrich et al. 2008). Thus, measures aimed at reducing threats to this species in Sierra Morena should be focused on reducing poaching, and the measures that have already been implemented to combat this threat should be toughened up. An increase in both awareness and surveillance, and a reduction in

Table 3 Cause-specific annual mortality rates ±95 % confidence interval recorded in the Doñana Iberian lynx population in 1983–1989 (Ferreras et al. 1992) (n=30) and in Doñana and Sierra Morena in 2006–2011 (this study) (n=39 in each population). Statistical differences between past and current (in both populations separately) values are compared through a Z test with a liberal p value of 0.15. Significant differences are presented in italic

Cause	Doñana	Doñana			Sierra Morena		
	1983–1989	2006–2011			2006–2011		
	AMR±CI 95%	AMR±CI 95%	Z	p	AMR±CI 95%	Z	p
Disease	0.03±0.06	0.07±0.05	0.8	0.44	0.04±0.04	0.2	0.82
Fight	0.03±0.06	0.01±0.02	0.6	0.57	0.03±0.03	0.0	1.00
Poaching	0.15±0.13	0.01±0.02	*2.1*	*0.04*	0.06±0.05	1.2	0.23
Car	0.06±0.08	0.01±0.02	1.1	0.28	0.01±0.03	1.1	0.28
Wells	0.03±0.06	0.00	1.0	0.34	0.00	1.0	0.34
Unknown	0.06±0.08	0.01±0.02	1.1	0.28	0.05±0.05	0.2	0.86
Total	0.37±0.14	0.12±0.07	*2.4*	*0.02*	0.19±7	*1.7*	*0.10*

the potential sources of lynx–human conflicts that could encourage poaching, are vital (Simón et al. 2013; Garrote et al. 2013). At least one mortality case due to fights in Sierra Morena was caused by territorial individuals attacking a subadult entering their home ranges. Similar behavior has been described in the Eurasian lynx (*Lynx lynx*) (Mattisson et al. 2013).

The significant decrease in the AMR in the Doñana population over the last two decades has been achieved above all by the reduction of the main anthropogenic threats described by Ferreras et al. (1992) (Table 3). Even though effective actions against poaching were considered unrealistic in the past (see Ferreras et al. 2001), our data show that the AMR due to poaching has decreased significantly in this population (Table 3). The decrease in AMR due to poaching between the two periods is still significant if we include the two doubtful cases of intraspecific fight into the poaching group (Z=1.8; p= 0.07). This decrease probably mirrors a change in the attitude of the local population, at least in part achieved through the poaching control program of the ILLP (López-Parra et al. 2012; Simón et al. 2013). Our results support the idea that the Doñana Iberian lynx population exhibits now a different spatial dynamic from that described two decades ago (López-Parra et al. 2012). Drowning in artesian wells was a cause of mortality recorded in 1983–1989 that did not occur during our study period, probably in part because corrective measures were adopted at the beginning of the ILLP (i.e., the removal or covering of wells).

The mortality caused by disease is a concern in the Doñana population. Our results reveal an increase in this factor that could be attributable to four nonexclusive reasons: (1) greater contact rates between lynx and reservoir species, (2) higher intraspecific contact rates that could help spread disease in the population, (3) a generalized immunosuppression, and (4) a relative increase in this final factor as a result of the decrease in nonnatural causes of mortality. Regarding the first possibility, the abundant wild and domestic carnivores and ungulates in Doñana have been identified as potential disease reservoirs in the Iberian lynx (Aranaz et al. 2004; López et al. 2009; Meli et al. 2009, 2010). Although there are no data suggesting an increase in the abundance of these species in the area over the last two decades, the Iberian lynx has begun to occupy highly humanized areas in this period (thereby increasing the amount of contact it has with domestic animals). Nevertheless, the Sierra Morena population is also occupying a highly humanized area (Garrote et al. 2013), but AMR due to diseases is lower there than in Doñana. The second option is also likely, mainly in areas such as El Aljarafe and Moguer, where Iberian lynx numbers have most increased in the past decade (Simón et al. 2013). This increase in the density of individuals favors the spread of infectious diseases that can be transmitted by direct contact. Finally, there is increasing evidence to support the theory that the Doñana Iberian lynx population is being affected by a generalized immunosuppression (Peña et al. 2006; Palomares et al. 2012). Our results agree with this possibility since (1) the majority of deaths provoked by disease (71 %) recorded in this study were not linked to old age, and (2) 30 % of these deaths were caused by opportunistic pathogens (usually nonlethal for immunocompetent individuals). One potential factor underlying this immunosuppression is the high levels of inbreeding reported in the Doñana Iberian lynx population (Godoy et al. 2009; Palomares et al. 2012), as this factor is a recognized immunosuppressor in many mammals (Acevedo-Whitehouse et al. 2003; Ross-Gillespie et al. 2007). The genetic reinforcement program implemented by the ILLP in Doñana (Ruiz et al. 2009; Simón et al. 2012), however, is expected to reduce this and other potential negative effects of inbreeding. Under this scenario, efforts to conserve the Doñana Iberian lynx population in the coming decade should be focused on (1) maintaining low levels of anthropogenic threats to the population and (2) decreasing the risk of mortality caused by infectious diseases. To achieve the first goal, actions designed to decrease poaching should continue and even be reinforced wherever necessary, while success in terms of the latter goal will depend on both the continuation of the genetic reinforcement program and more intense research into the potential causes of immunosuppression.

To sum up, our results identified disease and poaching as the most significant causes of mortality currently affecting the Iberian lynx population. Hence, future conservation actions should mainly focus on these two factors. Moreover, a demographic analysis, such as a PVA, considering fecundity, sex, age structure, etc., would provide useful information about the impact of the different causes of mortality on the population. Finally, given that causes of mortality may differ from one population to another within the same species, extrapolation from data from other populations should be avoided.

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CAPITULO 5

El conflicto hombre-felino como nuevo hándicap para la conservación del críticamente amenazado lince ibérico.

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El conflicto hombre-felino como nuevo hándicap para la conservación del críticamente amenazado lince ibérico.

La mayoría de los estudios de depredación de felinos sobre el ganado se centran en las especies de grandes felinos, siendo muy escasa la atención prestada a este tipo de conflictos en especies menores. El lince ibérico (*Lynx pardinus*) es un felino de mediano tamaño del que no se había documentado la existencia de conflictos con los humanos por este motivo. Sin embargo, en paralelo al incremento del área de presencia de la especie en Andújar-Cardeña, se ha producido un incremento de los ataques de lince ibérico sobre el ganado domestico. El seguimiento de los episodios de depredación del lince ibérico sobre el ganado durante 6 años, reveló un total de 40 ataques en los que se produjeron 716 muertes (31 ataques sobre aves de corral y 9 sobre corderos). Aunque la mayoría de los ataques (78%) fueron sobre aves de corral, la depredación sobre los corderos generó mayores pérdidas económicas, principalmente en aquellos rebaños manejados en extensivo (4,6 veces más pérdidas que los rebaños manejados en semi-extensivo). Para mitigar las consecuencias de este conflicto entre humanos y lince ibérico en el área, se estableció un programa de prevención y compensación. En el caso de los ataques sobre aves de corral, tras el pago de los daños, y el correcto cerramiento de los gallineros el conflicto desapareció casi en la totalidad de los casos .Dado que este tipo de conflicto puede convertirse en un impedimento grave para el futuro de la conservación de la especie de felino más amenazado del mundo, la gestión de este problema debe centrarse en anticipar y prevenir los posibles conflictos que pudieran surgir como consecuencia de la colonización, por parte del lince ibérico, de nuevas áreas humanizadas.

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SHORT COMMUNICATION

Human–felid conflict as a further handicap to the conservation of the critically endangered Iberian lynx

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Abstract Most studies on felid depredation of livestock have focused on big cats, and little attention has been paid to this type of conflict in smaller species. The medium-sized Iberian lynx (*Lynx pardinus*) is not thought to be affected by conflict with humans. However, parallel to an increase in the range of the Iberian lynx in Andújar-Cardeña, an increased incidence of Iberian lynx attacks on livestock has been recorded. A 6-year overview of Iberian lynx predation on livestock in this population shows a total of 40 attacks involving 716 kills (31 attacks on poultry and nine on sheep). Although the majority of these attacks (78 %) were carried out against poultry, sheep depredation resulted in higher economic losses, mainly in extensive flocks (4.6 times more than semi-intensive flocks). An effective compensation program has been implemented in order to mitigate the consequences of the human–lynx conflict in this area. Given that this sort of conflict could become an acute impediment to future conservation of the most endangered felid, managers should anticipate and prevent the potential conflicts that could arise as Iberian lynx colonizes more developed areas.

Keywords Human–felid conflict · Iberian lynx · *Lynx pardinus* · Livestock predation · Carnivores

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Introduction

Human–carnivore conflicts that lead to direct persecution causing increased mortality and the risk of extinction (Woodroffe and Ginsberg 1998) are one of the best-known stumbling blocks in the conservation of certain carnivore species (Treves and Karanth 2003). Wild felids are no exception since many readily kill livestock when opportunities arise, thereby provoking reprisals from the people most affected (Polisar et al. 2003; Andrén et al. 2006; Garrote 2012). For instance, anthropogenic action as a response to livestock attacks has been found to be the prime cause of mortality in some felid populations of species such as cheetah (*Acynonix jubatus*) (Marker et al. 2003), snow leopard (*Panthera uncia*) (Oli et al. 1994), and tiger (*Panthera tigris*) (Miquelle et al. 2005).

The majority of studies on felid attacks on livestock have focused on big cats and little attention has been paid to this type of conflict in smaller species (see Löe and Röskaft 2004; Loveridge et al. 2010). The small-to-medium-sized cats of the genus *Lynx* are not thought, generally, to enter into conflict with humans (Inskip and Zimmerman 2009), probably because it is known that they prefer to prey on lagomorphs (Sunquist and Sunquist 2002). However, in some Eurasian lynx (*Lynx lynx*) populations, human–felid conflict has been shown to be important (Odden et al. 2006). The smaller and critically endangered Iberian lynx (*Lynx pardinus*) is likewise not thought to be affected by conflict with humans (Inskip and Zimmerman 2009). This species is the most endangered felid species in the world (IUCN 2011), and less than a decade ago (Guzmán et al. 2004), its populations had reached a new low (160 individuals in two isolated populations). Huge efforts are currently being made to aid its recovery (Simón et al. 2012). The lack of information about potential attacks of Iberian lynx on livestock has generated the assumption that these attacks do not

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take place. However, as a result of the close monitoring of the Iberian lynx population carried out by the Iberian Lynx Life Project (ILLP) (see Simón et al. 2012), an increased incidence of Iberian lynx attacks on livestock has been recorded. These attacks are generating greater hostility to the Iberian lynx among the local population, which could threaten its survival. Consequently, a prevention and compensation program was implemented to compensate farmers for the livestock killed by Iberian lynx attacks. Farmers affected by these attacks on livestock contact ILLP personnel, and after verification, animals killed by lynx are replaced, and farm fences are fixed to prevent lynx from entering, when possible.

A better understanding of this conflict is essential if we are to find solutions that can be implemented as part of Iberian lynx conservation programs. In this study, we provide a 6-year overview of Iberian lynx predation on livestock in Andújar-Cardeña population and its consequences for the conservation of this threatened species.

Methods

The study area (2,600 km^2) is located in the eastern Sierra Morena (Southeast Spain), harboring the Andújar-Cardeña Iberian lynx population. It is a hilly area covered by well-preserved Mediterranean forests and scrubland. Large game reserves are the main land use. The eastern area is a developed area known as Viñas de Peñallana, with many small dwellings in 1–50 ha plots with small poultry coops housing up to 50 chickens. During the study period, six sheep flocks were present in the area with different management: (1) two flocks of 43 and 300 sheep that spent nights in a fold and were surveyed by a shepherd with dogs during daytime (semi-intensive) and (2) four flocks of 104, 320, 500, and 500 sheep grazing free over a large tract (extensive).

Between July 2006 and March 2012, we recorded and verified all reported attacks by Iberian lynx on livestock from the Andújar-Cardeña Iberian lynx population. The verification consists of a visit by an ILLP member who registers the date, the number of kills, the species preyed upon, and the preventive measures that are necessary to prevent future attacks. Only attacks that could be unambiguously attributed to Iberian lynx (identification by footprints, scats, photographs, radio tracking, or by the distinctive marks left on uneaten animals) are considered to be verified. Predated coops had 20–200 m perimeter and were 1.5 m high. When possible, the improvements on the coops were performed by covering all opened areas with mesh. When coops were too large for this modification, a mesh projection of 50 cm was added to the coop perimeter.

Results

A total of 40 attacks involving 716 kills were recorded during the study period: 31 attacks on poultry (chickens, turkeys, and doves) and nine on sheep. The average number of birds killed in each attack was 20.7 individuals (n=31 attacks; 1–50 individuals; standard error (SE) 13.88). In all, 61 % of attacks on poultry (n=19) occurred between April and July (Fig. 1); no attacks on poultry were recorded in January or February. A total of 64.5 % (n=20) of attacks on poultry occurred in Viñas de Peñallana, the rest (n=11) occurring in coops in private hunting estates. Total economic losses due to attacks on poultry were 3,985 €; the mean loss (±SE) was 128.5±103.1 €, and the maximum losses per attack were 525 €. A total of 22 coops were modified: eight completely closed and 14 with a mesh projection. Out of the eight enclosed coops, two suffered new attacks before modifications were completed. After modifications were completed, no attacks occurred. Two coops repaired with mesh projection were attacked again due to structural damage, and one because owners had removed chickens from the coop. Total economic cost due to coops modification was 7,376 €, and the mean loss (±SE) was 461±182.1 €.

During the study period, a total of seven different Iberian lynx (four adult males, two subadult males, and one subadult female) were identified attacking coops. These individuals could be identified by means of radio tracking, photo trapping, or direct observation inside the coops. One radio-tagged individual was detected entering coops on six occasions.

Attacks on sheep were usually multiple predation events on the same flock in successive days; nevertheless, each multiple event was considered as just a single attack. All predated ungulates were lambs of less than 1 month of age, and all attacks occurred between December and June (Fig. 1). The average number of lambs killed in each attack was 8.11 individuals (n=9 attacks; 2–18 individuals; SE

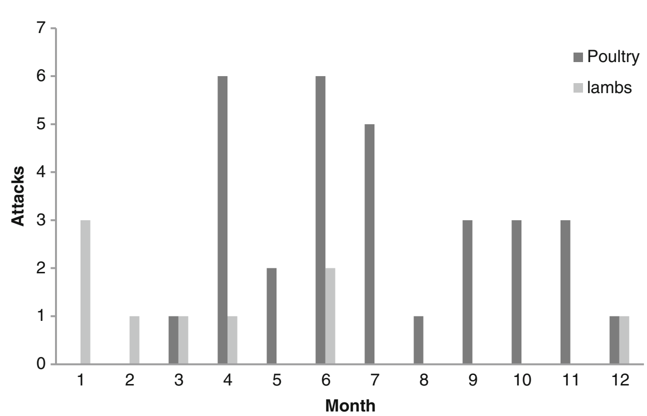

Fig. 1 Distribution of attacks (poultry and lambs) in months (January 1 to December 12)

5.64). A total of 18 % of the lambs killed (n=13) took place in semi-intensive flocks (n=4 attacks), whereas the other 82 % (n=60) were produced in extensive ones (n=5 attacks). Total economic losses due to lamb depredation were 4,380 € (60 €/lamb): 780 € in semi-intensive flocks and 3,600 € in extensive flocks. The mean loss (±SE) was 195±157 € per attack in semi-intensive flocks and 720±360 € in extensive flocks. The maximum losses per attack were 360 and 1,080 €, respectively.

Discussion

This is the first study reporting Iberian lynx attacks on livestock. The historical lack of information regarding Iberian lynx predation on livestock is most likely attributable to the fact that for decades, most studies on Iberian lynx ecology have been historically conducted inside Doñana National Park, where negligible amounts of livestock are available as prey. However, long-term Iberian lynx conservation projects have been developed over the last decade over the species' entire distribution range, thus allowing identification of areas where attacks on livestock have occurred. Moreover, the range of the Iberian lynx in Andújar-Cardeña has increased from 11,900 ha and 59 individuals in 2002 to 26,000 ha and 179 individuals in 2010 (Simón et al. 2012). Under this expansive scenario, the lynx has occupied a developed area (about 10 % of the occupied territory) where there is a high abundance of unprotected livestock, facilitating the attacks that provoke human–felid conflict (Kolowski and Holekamp 2006).

Although the majority of the attacks (78 %) were against poultry, total economic losses and losses per attack were higher in lamb depredation. Nonetheless, all known Iberian lynx killed as a response to attacks on livestock have been provoked by owners of depredated coops; two cases were identified by the ILLP radio-tracking program in Sierra Morena. The compensation program started in 2006 to offset the damage caused by the Iberian lynx. No further poaching cases associated with the conflict between humans and lynx have been detected since 2008, despite the fact that between 43 and 50 % of the lynx population inhabiting semi-humanized areas is being tracked by the radio-monitoring program since that year. Interestingly, we have released three individuals trapped in five different coops during the last year (thanks to the collaboration of the owners). Compensating losses is a necessary and effective measure in a short-term perspective; nevertheless, in a long-term perspective, the best strategy would be to pay for preventive measures due its effectiveness and relative low cost. After compensating losses and repairing coops, the conflict usually disappears.

Although our data do not allow definitive conclusions, they suggest that males, irrespective of their age, are more prone to attack coops than females. Similarly, the record of a single individual committing six attacks could underscore the theory of the "problem animal" (Linnell et al. 1999) that some particular animals are more prone to prey on livestock. Regardless, more research is needed in order to make solid conclusions.

Iberian lynx depredation over domestic ungulates is similar to that reported in big cats in (1) the selection of young domestic ungulates (Michalski et al. 2006), (2) the seasonality of attacks during the lambing season (Palmeira et al. 2008), and (3) the higher incidence of attacks in extensive and non-surveyed flocks with low control level (Thirgood et al. 2005). During our study period, the first detected attack on extensive sheep flocks took place in 2011 due to, prior to that, the distribution of the Iberian lynx in Andújar-Cardeña did not coincide with extensive sheep flocks focused on reproduction (to produce lambs for human consumption). We consider that loss compensation is a good measure to avoid human–felid conflict in the case of depredation on semi-intensive flocks (Linnell et al. 2012) because the cost is reasonable (few lambs lost, with sufficient compensation for the owners). In depredation on extensive flocks, however, economic losses are high, and compensation usually does not offset the loss for the affected owners. Thus, it is necessary to find a solution to minimize attacks on extensive flocks. As a preventive measure, the effectiveness of the installation of electric fences aimed at preventing Iberian lynx incursions will be tested. Similar experiments to prevent attacks by predators have been performed with varying degrees of success (Linhart et al. 1992; Silveira et al. 2008). An additional goal of these preventative measures is to encourage a change in the management of flocks, which would inherently reduce the vulnerability of sheep to future attacks.

The problem of predation on lambs cannot be considered as very serious in the Andújar-Cardeña Iberian lynx population, since just two extensive flocks with lambs occur in the area, and the economic cost of the damage is not high. Similarly, in the Guadalmellato Iberian lynx reintroduced population (Córdoba; see Simón et al. 2012), attacks on sheep have already been recorded despite the scarcity of flocks. However, there are potential reintroduction areas where the presence of extensive flocks is common. For instance, at least 15 extensive flocks are present in the Guarrizas (Jaen) reintroduction area.

The hostility of the local human population could have serious negative effects on the future of conservation of this species. In the current scenario of an expanding population, conservation managers should anticipate the potential conflicts that could arise as lynx colonize more humanized areas through the implementation of preventative measures such as the improvement of coops and folds for livestock susceptible to attacks and the promotion of more intensive management of extensive flocks. Therefore, in light of the results we present here, we suggest that (1) provisions for compensation, which are generally lacking at present (ICNB 2008; MARM 2008), should be included in all future Iberian lynx conservation plans; (2) a compensation and prevention program should be included in Spanish and Portuguese conservation laws to ensure that there will be sufficient funding to solve this problem if and when it reappears; and (3) the potential conflicts from lynx depredation on livestock should be considered when assessing the suitability of new areas for Iberian lynx reintroduction.

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CAPITULO 6.

Marcha atrás del declive del amenazado lince ibérico.

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Marcha atrás del declive del amenazado lince ibérico.

El lince ibérico (*Lynx pardinus*) fue declarado "en peligro crítico" por la Unión Internacional de Conservación de la Naturaleza en el año 2002. En una publicación reciente se llevó a cabo una evaluación de los esfuerzos aplicados en la conservación del lince ibérico, en la que se predijo una inminente extinción debido a una pobre gestión de la especie. Los autores usaron información incompleta y obsoleta sobre la reciente evolución de las poblaciones de lince ibérico a la hora de establecer estas conclusiones. Se describen en este trabajo los esfuerzos de conservación en curso y el estado actual de las poblaciones de lince ibérico. Tras la reclasificación del grado de amenaza del lince ibérico se pusieron en marcha programas de seguimiento intensivo de la especi, de recuperación del hábitat y de su presa principal (Oryctolagus cuniculus). La mayoría de los recursos económicos (63%) fueron invertidos en Andalucía, donde se detectaron las únicas dos poblaciones de la especie (Sierra Morena y Doñana). Financiados principalmente por la Unión Europea, los proyectos Life de conservación del lince ibérico en Andalucía se fundamentan en la ejecución de diversas acciones de conservación (acciones enfocadas en el incremento de la capacidad de carga y la reducción de amenazas), la evaluación de la efectividad de esas acciones, seguimiento de las poblaciones de conejo y lince y protección del hábitat. Como resultado de estas acciones, entre 2002 y 2010 la población de linces experimentó un incremento de 93 a 252 individuos y de 29.300 a 70.300 ha en la superficie ocupada, se incrementó la diversidad genética de la población de Doñana mediante la traslocación de 4 individuos procedentes de la población de Sierra Morena y se crearon dos nuevas poblaciones mediante reintroducción en Sierra Morena. Cualquier proyección de la probabilidad de extinción de la especie debe incorporar los datos actuales de todas las poblaciones existentes.

Reverse in the Decline of the Endangered Iberian Lynx

The Iberian lynx (Lynx pardinus) was declared critically endangered by the International Union for the Conservation of Nature (IUCN) in 2002. In a recent publication an assessment of Iberian lynx conservation efforts was conducted and predicted its imminent extinction due to poor management. Nevertheless, the authors of this report used incomplete and out-dated information on the recent evolution of Iberian lynx populations to reach these conclusions. We provide here an overview of on-going conservation efforts and the current status of the Iberian lynx. After the species' critically endangered status was recognized, intensive monitoring and habitat and prey (wild rabbit Oryctolagus cuniculus) restoration programs began. Most resources (63%) have been invested in Andalusia, where the species' two remaining populations live (Sierra Morena and Doñana). Funded mainly by a European Union Life project, the project for the conservation of Iberian lynx in Andalusia consists of accumulated conservation actions (actions focused on increasing the carrying capacity and decreasing threats), evaluations of the effectiveness of these actions, the monitoring of rabbit and lynx populations by the same multidisciplinary team, and habitat protection. As a result of these actions, in the period 2002–2010 lynx numbers rose from 93 to 252 and the occupied area increased from 29,300 to 70,300 ha. Genetic diversity in the Doñana population has increased due to the translocation of four individuals from Sierra Morena. Two new populations have been created by reintroduction in Sierra Morena. The true numbers of populations in the area occupied by Iberian lynx have increased dramatically over the past nine years, probably as a result of these diverse and comprehensive conservation efforts. Meaningful projections of extinction probabilities must thus incorporate all current data corresponding to all populations.

Comment

Reverse of the Decline of the Endangered Iberian Lynx

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Introduction

The Iberian lynx (*Lynx pardinus*) was declared critically endangered by the International Union for the Conservation of Nature (IUCN) in 2002, and the species is a flagship for conservation in Iberia. Palomares et al. (2011) conducted an assessment of Iberian lynx conservation efforts and predicted imminent extinction due to poor management. These authors based their inferences on information collected before the most substantial conservation programs began and extrapolated data from a nonrepresentative segment of the smaller of 2 remaining populations to model extinction probabilities for the species. The authors did not use available data from the first 9 years of an ongoing 14-year spatially extensive conservation and monitoring LIFE project (European Union funded projects for environmental and nature conservation) for the Iberian lynx. Thus, they overlooked substantial increases in lynx abundance, number of populations, and distribution over the past 5 years. Here, we provide an overview of ongoing conservation efforts and the current status of the Iberian lynx.

Conservation History

In the 1960s researchers realized both abundance and distribution of the Iberian lynx had decreased dramatically since the early 20th century (Valverde 1963; Delibes 1979). However, conservation plans were not implemented until 1980. Many early conservation efforts were ineffective (Palomares et al. 2011), most likely due to insufficient funding. In 1994 the European Union and several Spanish and Portuguese government agencies committed €1,306,021 to Iberian lynx conservation (Table 1). During the 1990s widespread presence–absence surveys showed that most populations were extirpated (Gil-Sánchez & McCain 2011), and little research attention was dedicated to the species outside Doñana National Park (DNP) in southern Spain. After the species' critically endangered status was recognized by Guzmán et al. (2004), intensive monitoring and habitat and prey (rabbit [*Oryctolagus cuniculus*]) restoration programs began. Most resources (63%) have been invested in Andalusia (€59,016,062) (Table 1), where the only 2 remaining populations of the species (Sierra Morena and Doñana) (Fig. 1) were identified in 2002.

Palomares et al. (2011) criticized management plans for lacking continuity and being applied over too small an area. However, the European Union recently funded the third consecutive 5-year LIFE project for the conservation of Iberian lynx in Andalusia (ILLP) (14 years, 2002–2016). The ILLP consists of accumulated conservation actions (actions focused on increasing carrying capacity and decreasing threats), evaluations of the effectiveness of these actions, monitoring of rabbit and lynx populations by the same multidisciplinary team, and protection of 180,000 ha of habitat that encompasses 98% of the currently occupied range of both remaining populations (Simón et al. 2009). The Iberian Lynx Conservation Project in Lugar Nuevo has conducted similar work since 2002 in the remaining 2% (3243 ha) of the species' currently occupied

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Table 1. LIFE projects focused on the conservation of the Iberian lynx in the Iberian Peninsula.

Project	*Start year*	*End year*	*Budget (€)*	*Action region*	*Search for lynx*	*Habitat management*	*Lynx monitoring*	*Reintroduction-area evaluation*
Conservation of the Iberian lynx	1994	1996	117,021	Portugal	X			
Lince/Castilla León—Conservation of the Iberian lynx—Castilla y Léon	1994	1998	112,000	Castilla y León (Spain)	X			
Conservation of the Iberian lynx (Comunidad de Madrid)	1994	1998	90,000	Madrid (Spain)	X			
Conservation of the Iberian lynx	1994	1998	72,000	Madrid (Spain)	X			
Conservation of the Iberian lynx	1994	1998	36,000	Madrid (Spain)	X			
Conservation of the Iberian lynx (Andalusia)	1994	1998	444,000	Andalucía (Spain)	X			
Conservation of the Iberian lynx (Castilla la Mancha)	1994	1998	306,000	Castilla-La Mancha (Spain)	X			
Conservation of the Iberian lynx (Extremadura)	1994	1998	129,000	Extremadura (Spain)	X			
Conservation of the Iberian lynx (Extremadura)	1995	1998	159,000	Extremadura (Spain)	X			
Conservation of the Iberian lynx (Castilla la Mancha)	1995	1998	382,000	Castilla-La Mancha (Spain)	X			
Conservation of the Iberian lynx (Castilla y Leon)	1995	1998	139,000	Castilla-León (Spain)	X			
Conservation of the Iberian lynx (Andalusia)	1995	1998	550,000	Andalusia (Spain)	X			
Conservation of the Iberian lynx (Madrid)	1995	1998	46,000	Madrid (Spain)	X			
Conservation of the Iberian lynx	1995	1998	91,000	Madrid (Spain)	X			
Conservation of the Iberian lynx	1995	1998	111,000	Madrid (Spain)	X			
Conservation of the Iberian lynx	1999	2001	404,185	Portugal	X			
Conservation of the Imperial Eagle, Black Vulture, Black Stork, and Iberian lynx	1999	2002	1,709,278	Castilla-La Mancha and Extremadura (Spain)	X			
Conservation of lynx pardina in Extremadura	1998	2003	1,377,197	Extremadura (Spain)	X			
Land acquisition of strategic areas in Doñana district	1999	2003	1,258,859	Andalusia (Spain)		X		
Conservation of the threatened fauna and vegetation in the Cabañeros National Park	1999	2003	6,490,930	Castilla-La Mancha (Spain)	X	X		
Population recovery of Iberian lynx in Andalusia	2002	2006	9,285,714	Andalusia (Spain)	X	X	X	X

continued

Table 1 (continued)

Project	*Start year*	*End year*	*Budget (€)*	*Action region*	*Search for lynx*	*Habitat management*	*Lynx monitoring*	*Reintroduction-area evaluation*
Conservation of the Iberian lynx in Montes de Toledo-Guadalmena	2002	2006	1,537,284	Castilla-La Mancha (Spain)	X	X		
Conservation of the Iberian lynx	2006	2007	493,443	Portugal	X	X		
Iberian lynx conservation in Lugar Nuevo*	2002	2011	5,000,000	Andalusia (Spain)		X	X	
Conservation and reintroduction of the Iberian lynx in Andalusia	2006	2011	25,971,489	Andalusia (Spain)		X	X	X
Conservation of the Iberian lynx and the Black Vulture	2010	2012	2,640,556	Portugal		X		X
Conservation of Mediterranean priority species in Castilla-La Mancha	2007	2012	3,699,135	Castilla-La Mancha (Spain)	X	X		
Recovering Iberian lynx distribution in Spain and Portugal	2011	2016	34,015,188	Spain and Portugal		X	X	X
			Total 94,000,279					

*Not a LIFE project.

range on land adjacent to properties managed by ILLP in Sierra Morena (Guzmán et al. 2010).

Conservation Efforts

The main threats to the persistence of the Iberian lynx are low abundance of rabbits (primary prey), increased mortality due to human activity and diseases, decreased genetic diversity, and low number of populations (Rodríguez & Delibes 1992; Guzmán et al. 2004; Godoy et al. 2009). The ILLP seeks to decrease the magnitude of these threats through use of knowledge of Iberian lynx ecology and adaptive management (Salafsky et al. 2002; Sutherland et al. 2004) and by finding common points of interest among landowners, hunters, and conservationists (Mattson et al. 2006). Approximately 80% of Iberian lynx occur on private property, most of which is managed specifically for hunting of red deer (*Cevus elaphus*), Red Partridges (*Alectoris rufa*), and rabbits. Therefore, conservation agreements with landowners are essential. They allow development of site-specific actions for increasing abundance of rabbits through both habitat improvement (constructing predator-proof rabbit-rearing enclosures, extensive underground rabbit warrens, brush piles, and water sources and clearing brush and pruning forest to increase herbaceous forage) and restocking of rabbits (from nearby agricultural lands), actions that benefit landowners (increased revenue from rabbit hunting) and lynx. The conservation agreements also facilitate land uses that preserve Mediterranean scrubland and grant project personnel access to private lands (Simón et al. 2009).

Since 2002 the ILLP has improved the quality of 158,173 ha of habitat in 46 territory recovery units (areas ≥500 ha in which territories of breeding-aged females are restored) and restocked approximately 55,000 wild rabbits. Currently 158 conservation agreements pertain to over 180,000 ha. Rabbit densities have significantly increased in Sierra Morena (from 1.52/ha in 2003 to 4.05/ha in 2010; paired t test: $t = -4.11$, df = 1,32, $p < 0.01$) and remain stable in areas of Doñana where territory recovery units have been restored (1.43/ha in 2003 and 1.77/ha in 2010; $t = 0.94$, df = 1,227, $p = 0.35$). Inside DNP, however, where rabbit restocking has occurred but habitat improvement of territory recovery units has been limited, rabbit densities have decreased slightly from 1.5/ha in 2003 to 0.77/ha in 2010 ($t = -1.4$, df = 1,1026, $p = 0.17$).

The ILLP has addressed natural and human-caused mortality of lynx. Public outreach, patrols for illegal poaching, and increased actions to increase the safety of animals crossing roads (i.e., under- and overpasses for animals, reduced speed zones, and fencing and reflective lighting designed to discourage lynx from crossing roads in dangerous areas) have greatly decreased anthropogenic lynx mortality (Simón et al. 2009). In Sierra Morena,

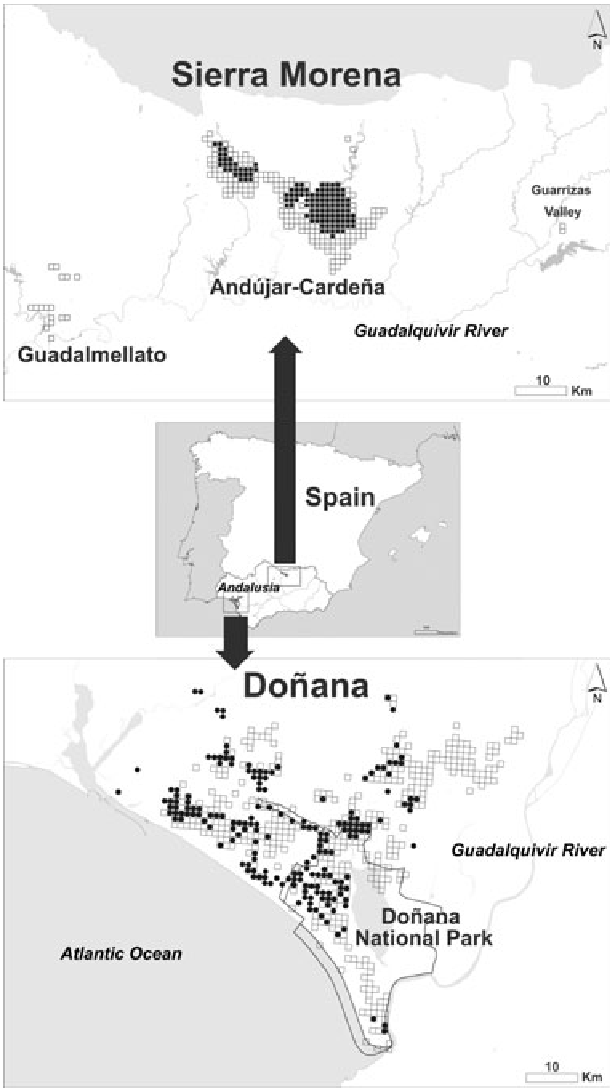

Figure 1. Distribution of Iberian lynx estimated from camera-trapping data and locations of systematic surveys for Iberian lynx scats in the 2 areas where the last 2 populations exist (150 km apart): Doñana and Sierra Morena, Andalusia, Spain (dots, occupied 1 × 1 km grid cells in 2002; open squares, occupied 1 × 1 km grid cells in 2010; open-square clusters to the east and west of the core Sierra Morena population, areas where translocated animals were released in 2010 and 2009, respectively) (data from Ministerio de Medio Ambiente and Consejería de Medio Ambiente de la Junta de Andalucía).

human-caused mortality decreased from 40% of radio-collared Iberian lynx ($n = 10$) in 1992–1995 (Rodríguez & Delibes 1995) to 7.4% ($n = 27$) in 2006–2010 (G test: $G = 32.7$, df $= 1{,}1$, $p < 0.01$). In Doñana deaths of radio-collared lynx caused by humans decreased from 58.4% ($n = 30$) in 1983–1989 (Ferreras et al. 1992) to 11.1% ($n = 27$) in 2006–2010 ($G = 53.3$, df $= 1{,}1$, $p < 0.01$). The ILLP conservation medicine program has minimized major risks from infectious diseases (López et al. 2009, 2011; Meli et al. 2009). Genetic diversity in the Doñana population was increased (Godoy et al. 2009; Palomares 2009) through the translocation of 4 individuals (3 males, 1 female selected on the basis of their ancestral lineage and reproductive, social, and health status) from Sierra Morena to Doñana (Ruiz et al. 2009*a*, 2009*b*). As a result, there are currently 8 F1 and 8 F2 crossed individuals in the Doñana population.

To decrease extirpation risk due to low numbers of populations, the reintroduction program has begun to create new populations in areas where Iberian lynx were recently extirpated. Sites for reintroduction were selected through detailed site evaluations (García & Gil-Sánchez 2008), following guidelines from the IUCN (1998). Seventeen Iberian lynx have been released in 2 portions of the former range (approximately 50 km to the east and west of the remnant Sierra Morena population) (Fig. 1). Eleven of the 12 Iberian lynx released into Guadalmellato have remained within the reintroduction area, and 4 females have raised 10 offspring. Five Iberian lynx were released in Guarrizas, 2 of which were the first captive-raised individuals released into the wild (Simón 2010). In addition, genetic samples have been preserved from >200 individuals (León-Quinto et al. 2009), and a captive-breeding program was initiated with individuals removed from the wild by ILLP (Vargas et al. 2008; Simón et al. 2009). By continuing these programs in 2011–2016, the ILLP hopes the Iberian lynx will be downlisted to the IUCN category endangered by 2016.

Monitoring

Palomares et al. (2011) suggest that managers working to conserve Iberian lynx have limited confidence in scientific knowledge and that few resources have been dedicated to monitoring the effectiveness of actions. The ILLP has a multidisciplinary team of research scientists who evaluate the effectiveness of all actions (e.g., Román et al. 2006; Simón et al. 2009; Gil-Sánchez et al. 2011). Moreover, all programs implemented through the ILLP have been reviewed by an international group of researchers and managers, and ongoing external cross-validation analyses (Gusset et al. 2010) are evaluating the effectiveness of ILLP actions. In the past, indirect methods, such as sighting reports and mailed surveys, were used to monitor Iberian lynx populations (i.e., Rodríguez & Delibes 1992); however, use of anecdotal data overestimates lynx abundance and distribution because species are misidentified and there are temporal and spatial inaccuracies (Guzmán et al. 2004; Gil-Sánchez & McCain 2011). Currently, camera-trap data collected following internationally standardized methods are used to estimate Iberian lynx abundance, distribution, home range, reproductive success, and individual body condition (Guzmán

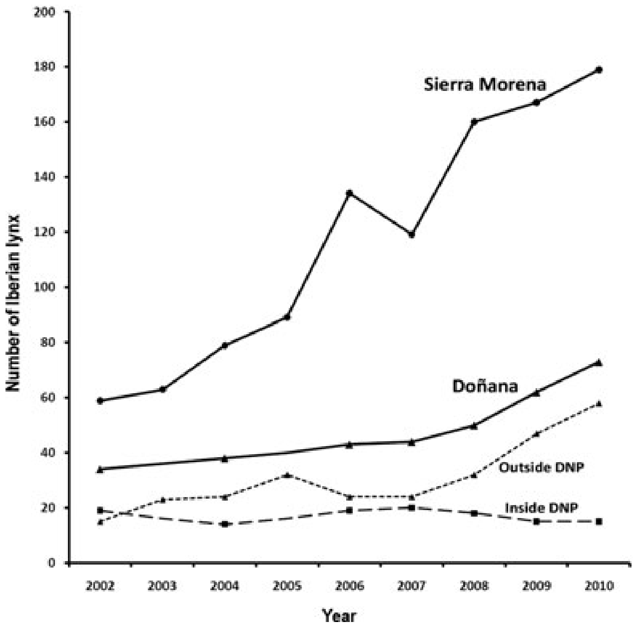

Figure 2. Minimum number of Iberian lynx in the last 2 populations in Doñana and Sierra Morena (Andalusia, Spain) photographed during camera-trap monitoring in 2002–2010 (DNP, Doñana National Park). Sampling effort in Doñana was constant among years, except in 2003 and 2005, for which information from inside DNP is lacking. Sampling effort in Sierra Morena was constant from 2004 to 2010; however, in 2002 and 2003 about 10% of the occupied area was not surveyed.

et al. 2004; Garrote et al. 2011; Gil-Sánchez et al. 2011). Rabbit populations were not adequately monitored in earlier projects, as Palomares et al. (2011) suggest; however, ILLP has developed a monitoring program that includes scientifically validated methods (e.g., indices of abundance per kilometer [Buckland et al. 2001], direct rabbit censuses [Moreno et al. 2007], and pellet and latrine counts [Ferreira et al. 2010]).

Population Trends

Between 2002 and 2010, the minimum number of camera-trapped individuals increased from 93 to 252 (Fig. 2) and the occupied area (estimated from camera-trapping data and systematic surveys for lynx scats [Gil-Sánchez et al. 2010]) increased from 29,300 to 70,300 ha (Fig. 1). The Doñana population increased from 34 to 73 individuals (Fig. 2) and the area they occupied increased from 17,400 to 44,300 ha (Fig. 1). Abundance was stable in 1980–2007, but almost doubled in 2007–2010 (Fig. 2). Lynx abundance inside DNP did not increase during this period, likely because of disease (López et al. 2009; Meli et al. 2010) and the fact that it is difficult to increase the abundance of rabbits in areas where habitat quality has not been increased (Delibes-Mateos et al. 2009). Palomares et al. (2011) stress establishing 10 breeding territories inside DNP to prevent extirpation of the Doñana population; however, this goal has been exceeded outside of the park. The increases in abundance, genetic diversity, and area occupied by the entire Doñana population currently represents the best demographic situation in the last 25 years (see Palomares et al. 1991; Ferreras 2001; Garrote et al. 2011). The larger Iberian lynx population in Sierra Morena has increased the most in terms of individuals (59–179 individuals) (Fig. 2) and area occupied (11,900–26,000 ha) (Fig. 1). Moreover, the 2 newly reintroduced populations further strengthen the Sierra Morena population because they have begun to exchange individuals and lynx are now distributed over a much larger area than in previous decades.

The current conservation status of the Iberian lynx is more positive than Palomares et al. (2011) describe. The use of incomplete (only the DNP segment of the Doñana population) and outdated (before 2005) information generated inaccurate conclusions regarding the extinction risk of the species (Palomares et al. 2011). The actual number of populations in and area occupied by Iberian lynx have increased dramatically over the last 9 years, likely as a result of diverse and comprehensive conservation efforts. Meaningful projections of extinction probability must incorporate all current data from all populations. The criticisms by Palomares et al. (2011) of resource management and the scientific knowledge of involved practitioners are personal opinions that are not supported by empirical data. The progress toward recovery of the Iberian lynx suggests that conservation efforts have been conducted in a successful manner. Furthermore, misrepresentation of efforts to conserve Iberian lynx and their population history may negatively affect public and professional perceptions and could reduce the probability of success of the conservation actions currently underway. The Iberian lynx is not free from the risk of extinction due to continued habitat loss, anthropogenic mortality, and diseases of both lynx and rabbits; however, the species‘ population trend has improved since comprehensive conservation programs for the 2 remaining populations were launched in 2002.

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CONCLUSIONES

CONCLUSIONES

1) La aplicación de análisis de captura recaptura a datos obtenidos mediante fototrampeo son adecuados para la estima de abundancia de las poblaciones de lince ibérico. La estima de la población de lince ibérico del área de Doñana en el año 2003 mediante este método arrojó indica una notable reducción de sus efectivos respecto desde la década de los 80 poniendo de manifiesto la crítica situación de la especie en el área de Doñana

2) En las estaciones de fototrampeo en las que se aplican atrayentes, se detectan en menor tiempo un mayor número de individuos y se obtienen un mayor número de capturas totales. Esto implica que el uso de atrayentes en las estaciones de fototrampeo incrementa la probabilidad de captura, lo que se traduce en estimas de mayor exactitud.

3) Las estimas de densidad de lince ibérico obtenidas mediante el método del conteo de excrementos, se relacionan positiva y directamente con las densidades mínimas obtenidas mediante el método de fototrampeo. El coste económico derivado de la aplicación del conteo de excrementos notablemente inferior al coste derivado de la aplicación del fototrampeo. El conteo de excrementos es un método económico que proporciona evaluaciones fiables de la abundancia de lince ibérico en grandes superficies.

4) Las enfermedades fueron la principal causa de muerte de las poblaciones de lince ibérico en su conjunto. Las enfermedades fueron la principal causa de muerte en la población de Doñana-Aljarafe, mientras que la caza ilegal fue la principal causa de muerte en la población de Sierra Morena. Las tasas de mortalidad actuales son significativamente inferiores a las detectadas en los años 80.

5) La mayoría de los casos de depredación de lince ibérico sobre animales domésticos se producen sobre aves de corral, y en menor medida sobre corderos. La aplicación de medidas de compensación y prevención son eficaces para minimizar el conflicto generado por la depredación del lince sobre las aves de corral. En el caso de los ataques a corderos es necesario desarrollar medidas de prevención de ataques eficaces.

6) Los esfuerzos de conservación y recuperación de las poblaciones de lince ibérico desarrollado en el siglo XXI han sido efectivos, logrando revertir el declive de sus poblaciones. Entre 2002 y 2010 la población de linces experimentó un incremento de 93 a 252 individuos y de 29.300 a 70.300 ha de superficie ocupada. Se incrementó la diversidad genética de la población de Doñana y se crearon dos nuevas poblaciones mediante reintroducción en Sierra Morena.

RESUMEN

El conocimiento de la distribución y abundancia de las especies, así como sus tasas de supervivencia y causas de mortalidad, juegan un papel importante a la hora de establecer sus requerimientos ecológicos, evaluar el estado de sus poblaciones y predecir la evolución de las mismas. Obtener esta información es particularmente difícil en el caso de los felinos silvestres debido a que suelen ser escasos y tienen hábitos elusivos.

El lince ibérico, *Lynx pardinus*, clasificado "En Peligro Crítico" por la UICN, está considerado el carnívoro más amenazado de Europa y la especie más amenazada de la familia Felidae. Endémico de la Península Ibérica y asociado al matorral mediterráneo, el lince ibérico es un especialista trófico, estrictamente dependiente del conejo de monte (*Orictolagus cuniculus*). Distribuido por toda la península ibérica hasta finales del siglo XIX, a mediados del siglo XX la especie presentaba una distribución restringida al cuadrante suroccidental de la península, reconociéndose la caza intensiva como la primera causa de extinción en este periodo.

En la década de los 80 se estimó una población de 1.000-1.200 linces (unas 350 hembras reproductoras), distribuidos en 48 áreas de presencia estable, agrupadas en 9 poblaciones aisladas. La metodología utilizada en este estudio, la recopilación de avistamientos mediante entrevistas, probablemente llevó a una sobreestimación significativa de la abundancia y distribución de la especie y falló en reconocer la magnitud de su declive. En la década de los 90 se realizaron estudios parciales sobre la situación del Lince Ibérico en la Península Ibérica, en los que se apunta un descenso de las poblaciones de la especie y la reducción e incluso desaparición de las poblaciones de conejos en buena parte del área de distribución del lince ibérico. La pérdida de hábitat como consecuencia del cambio en los usos del suelo y, principalmente, la reducción de las poblaciones de conejo como consecuencia de las enfermedades, han sido argumentadas como principales causas de la desaparición del lince en la segunda mitad del siglo XX. Estos problemas han perdurado con el pasar de los años, pero la importancia relativa que cada uno de ellos ha tenido sobre la evolución de las poblaciones de lince ibérico ha variado a lo largo del tiempo y del espacio.

A principios del siglo XXI se estimó que la población de Lince ibérico en la Península Ibérica estaba compuesta por entre 84 y 143 individuos y entre 26 y 30 territorios de hembras reproductoras. Su distribución se restringía a unos 500 km[2], divididos en 2 únicas poblaciones reproductoras en Doñana y Andújar-Cardeña (Sierra Morena Oriental), constatándose su extinción en Portugal. En esta ocasión se utilizaron diversas metodologías como la búsqueda que de excrementos y su posterior análisis genético y el fototrampeo, que permitieron eliminar fuentes de error en la identificación de la presencia de la especie.

Los trabajos que componen esta tesis doctoral se han desarrollado con el objetivo de cubrir las necesidades creadas a lo largo de una década de proyectos de seguimiento y conservación de lince ibérico. Su objetivo es conocer la distribución y abundancia de la especie, valorar la efectividad de las medidas de conservación desarrolladas hasta la fecha y obtener la información necesaria para establecer, reorientar o confirmar líneas de actuación. En este escenario, los objetivos de esta tesis doctoral son:

Capítulo 1) Determinar la validez de las técnicas de fototrampeo para la detección de lince ibérico y para estimar sus poblaciones mediante el uso de análisis de captura recaptura.

Capítulo 2) Valorar el efecto de los atrayentes sobre la efectividad de las cámaras trampa para detectar individuos de lince ibérico y su efecto sobre las subsiguientes estimas poblacionales.

Capítulo 3) Evaluar la precisión de los índices de abundancia obtenidos mediante conteo de excrementos como estimadores de densidad de Lince ibérico, y su potencial uso como alternativa económicamente rentable frente al uso de cámaras trampa.

Capítulo 4) Determinar las tasas de mortalidad de lince ibérico y sus causas en toda su área de distribución con el fin de evaluar y mejorar las medidas de conservación, determinar la importancia relativa de las diferentes causas de mortalidad entre las dos poblaciones actualmente existentes y analizar los posibles cambios en las tasas de mortalidad y sus causas en los últimos 20 años.

Capítulo 5) Exponer los resultados de 6 años de seguimiento de los eventos de predación de lince ibérico sobre ganado doméstico en la Sierra de Andújar, y describir el programa de prevención y compensación desarrollado para minimizar los daños producidos a los ganaderos y evitar muertes de linces por estas causas.

Capítulo 6) Finalmente, proporcionar una visión general de las iniciativas de conservación desarrolladas y de la situación del lince ibérico en la primera década del siglo XXI.

Para cubrir los objetivos de los capítulos 1 y 2 se utilizaron datos procedentes del fototrampeo para estimar las poblaciones de lince ibérico mediante la aplicación de análisis de captura-recaptura. En el caso del capítulo 1 se aplicó el fototrampeo sobre casi la totalidad del área de distribución de la especie en la población de Doñana. En el capítulo 2, se realizaron sendos muestreos de fototrampeo simultáneos (con atrayente y sin atrayente) en una finca privada en el área de Andújar-Cardeña. En el capítulo 3 se planteó una comparativa entre el método del conteo de excrementos y el fototrampeo, en la que se comprobó mediante un análisis de regresión simple si el método de conteo de excrementos es capaz de predecir las densidades de lince ibérico establecidas mediante fototrampeo, y se evaluó el coste económico de cada tipo de monitoreo. En el capítulo 4 se estimaron las tasas anuales de mortalidad de las poblaciones de lince ibérico y sus causas en toda su área distribución mediante la información obtenida de 78 individuos radiomarcados. En el capítulo 5 se recopiló la información referente a los episodios de depredación del lince sobre animales domésticos en el área de Andújar-Cardeña (Sierra Morena). Finalmente, en el capítulo 6 se describen los esfuerzos de conservación realizados durante la última década en el marco de los distintos proyectos de conservación desarrollados y sus el efecto sobre las poblaciones del lince ibérico

Los resultados obtenidos en el capítulo 1 demostraron que al igual que con otros felinos, la aplicación de análisis de captura recaptura a datos obtenidos mediante fototrampeo son adecuados para la estima de abundancia de las poblaciones de lince ibérico. La estima de la población de lince ibérico del área de Doñana arrojó una cifra de alrededor de 26 (SE=5.26) linces mayores de un año, lo que implicó una notable reducción de sus efectivos respecto desde la década de los 80, y cambios en la distribución espacial de la especie, poniendo de manifiesto la crítica situación de la especie en el área de Doñana.

En el capítulo 2 se comprobó como las estaciones de fototrampeo en las que se usan atrayentes, detectan en menor tiempo, un mayor número de individuos y obtienen mayores probabilidades de captura de los individuos, lo que se traduce en estimas de mayor exactitud. Por tanto, se pudo concluir que el uso de atrayentes en el fototrampeo incrementa la efectividad, precisión y eficiencia de las estimas de abundancia mediante captura-recaptura para el lince ibérico.

Hasta la fecha, el principal método de seguimiento de la evolución numérica de las poblaciones de Lince ibérico ha sido el fototrampeo. En el capítulo 3 se demuestra que el conteo de excrementos proporciona un índice fiable y económico de la distribución espacial de la densidad de las poblaciones de lince ibérico, comparado con la información obtenida mediante un método más caro como el fototrampeo. Ante un escenario de expansión de las poblaciones de lince ibérico el uso de métodos como el fototrampeo puede llegar a ser logística y económicamente inabarcable. El conteo de excrementos se presenta como una alternativa prometedora para establecer densidades de lince en grandes áreas.

Las acciones destinadas a reducir la mortalidad del lince ibérico llevadas a cabo en el marco de los proyectos de conservación, se diseñaron en base a los datos de mortalidad existente, procedente principalmente de la población de Doñana en la década de los 80. En el capítulo 4 se observó que en la actualidad, las enfermedades fueron la principal causa de mortalidad para toda la población en su conjunto y fue especialmente importante en la población de Doñana. Esta mortalidad en Doñana podría estar provocada por inmunosupresión debida al alto grado de consanguinidad que presentan los individuos de esta población. En Sierra Morena, fue la caza ilegal la principal causa de muerte detectada en la población. Las tasas anuales de mortalidad de ambas poblaciones obtenidas en este estudio fueron menores que las obtenidas 20 años atrás en el área de Doñana, único estudio previo de mortalidad de lince ibérico realizado en base a datos obtenidos con radioseguimiento, y por lo tanto comparable. Los resultados sugieren que la mejor estrategia para la conservación de esta especie es de concentrar las acciones en la disminución de los efectos mortales de las enfermedades y la caza furtiva.

Una de las acciones destinadas a reducir la caza ilegal es la creación del programa de compensación y prevención de los ataques de lince a animales domésticos. Los resultados del seguimiento de los episodios de depredación producidos por el lince en la población de Andújar-Cardeña durante 6 años (capítulo 5) indicaron que la mayoría da los ataques se produjeron sobre aves de corral (78%) y en menor medida sobre corderos. A pesar de ello, las pérdidas económicas fueron mayores en los casos de ataques sobre corderos. En el caso de los ataques sobre aves de corral, tras el pago de los daños y el correcto cerramiento de los gallineros, el conflicto desapareció casi en la totalidad de los casos. Sin embargo, en el caso de los ataques sobre corderos, principalmente sobre aquellos rebaños manejados en extensivo, las pérdidas económicas fueron mayores (720±360 € por ataque sobre rebaños en extensivo vs 128,5±103,1 € por ataque sobre aves de corral), y continúan sucediendo. Es necesario, por lo tanto, en este caso ensayar métodos de prevención que reduzcan el impacto de los ataques de lince sobre los corderos para minimizar así el conflicto con los ganaderos.

Durante la última década se ha desarrollado un plan continuo de conservación y recuperación de las poblaciones de lince estructurado alrededor de varios proyectos de conservación, recogido en el capítulo 6. Las principales líneas de actuación de estos proyectos, destinadas a minimizar la amenazas que afectaban a la especie, eran: 1) El incremento de la capacidad de carga de las áreas de presencia, principalmente mediante la recuperación de las poblaciones de conejo silvestre, 2) reducción de la mortalidad no natural, 3) establecimiento de un programa sanitario, 4) reforzamiento genético de la población de Doñana y 5) creación de nuevas poblaciones mediante reintroducción. La efectividad de las acciones fue evaluada mediante un programa de seguimiento de las poblaciones de lince ibérico (principalmente mediante fototrampeo) y de conejo silvestre. Como resultado de las acciones de conservación entre los años 2002 y 2010 el número mínimo de linces detectados mediante fototrampeo pasó de 93 a 252, y el área ocupada por la especie se incrementó de 29,300 a 70.300 ha. Además se inició el programa de refuerzo genético de la población de Doñana mediante la traslocación de 4 ejemplares provenientes de la población de Sierra Morena y se crearon dos nuevas poblaciones de lince ibérico en Sierra Morena mediante reintroducción. Todo ello ha puesto de manifiesto que es posible corregir la situación de partida, hacia una situación más optimista. A pesar de ello, el escenario en el que se encuentra la especie aún es inestable. Algunos de los conocidos factores de amenaza podrían desencadenar un proceso de extinción en cualquiera de las poblaciones. Así, la escasez de efectivos numéricos de la especie y de poblaciones, la pérdida de variabilidad genética, el riesgo de contraer enfermedades, la mortalidad no natural y las enfermedades víricas del conejo continúan amenazando al lince ibérico. La supervivencia de la especie a largo plazo requiere ineludiblemente la aplicación de medidas de conservación de manera continua y eficaz. Esto implica la necesidad de un seguimiento paralelo de la evolución de las poblaciones y de los factores que puedan incidir negativamente sobre estas. Debido a los potenciales efectos negativos que pudieran acarrear para la conservación de la especie, la obtención de información fiable debería ser un aspecto principal a la hora de diseñar y analizar los programas de seguimiento y de diseñar futuras acciones de conservación.

ABSTRACT

Knowledge of a species' distribution and abundance, as well as its survival rates and the main causes of mortality, plays an important role in identifying its ecological requirements, evaluating the state of its populations and forecasting their evolution in coming years. Nevertheless, obtaining this information is particularly difficult in the case of wild felines given that they are generally rare and often highly elusive.

The Iberian lynx (*Lynx pardinus)*, classified as Critically Endangered by the IUCN, is considered to be the most endangered European carnivore and the most threatened member of the Felidae family. Endemic to the Iberian Peninsula and closely tied to Mediterranean scrublands, this lynx is a trophic specialist and strictly dependent on the wild rabbit (*Oryctolagus cuniculus*). Found throughout the whole of the Iberian Peninsula at the end of the nineteenth century, by the mid-twentieth century this feline was confined to the southwest quarter of the Peninsula due in large part to intensive hunting.

In the 1980s the Iberian lynx population was estimated at 1,000–1,200 individuals (around 350 breeding females) grouped into 48 stable areas of occupation corresponding to nine isolated populations. Nevertheless, the methodology used to calculate these figures – a compilation of sightings derived from interviews – probably significantly overestimated both the species' abundance and range, and failed to detect the magnitude of its decline. In the 1990s partial studies were conducted on the state of the lynx's Iberian populations that recognised the decline in its populations, as well as the fall and even disappearance of rabbit populations over large areas of the lynx's range. The loss of habitat due to changes in land use and, above all, the fall in rabbit numbers as a result of disease, are generally cited as the main causes of the decline in lynx populations over much of its range in the second half of the twentieth century. These problems have not disappeared, even though their relative importance in the evolution of Iberian lynx populations has varied both spatially and temporally.

By the beginning of the twenty-first century the total number of Iberian lynxes in the Iberian Peninsula was calculated to be 84–143 individuals, including 26–30 territories with breeding females. Its distribution had contracted to 500 km^2 and just two breeding populations, Doñana and Andújar-Cardeña (eastern Sierra Morena), and it was extinct in Portugal. Various different methodologies were used to calculate these figures including the collection and genetic analysis of scats and camera-trapping that enabled errors in species identification to be avoided.

The work undertaken for this doctoral thesis were conducted to satisfy the requirements that have arisen as a result of ten years of lynx monitoring and conservation. Its main aims are to establish the species' distribution and abundance, evaluate the effectiveness of conservation measures carried out to date, and to generate information that will establish, redirect and endorse current lines of work. Specifically, the objectives of this thesis are as follows:

Chapter 1) Assess the validity of camera-trapping techniques in the detection of Iberian lynxes and in estimating population size using capture/recapture analysis.

Chapter 2) Evaluate how attractants influence the effectiveness of the camera-traps used to detect individual lynx and analyse their effect on resulting population estimates.

Chapter 3) Evaluate the accuracy of the abundance indices obtained through scat counts and their value as estimates of lynx densities, as well as their potential use as an inexpensive alternative to camera-traps.

Chapter 4) Assess Iberian lynx mortality rates and their causes throughout its distribution area in order to evaluate and improve conservation measures, determine the relative importance of each different cause of mortality in the two remaining populations, and analyse possible changes in mortality rates and causes over the last 20 years.

Chapter 5) Publish the results of six years of monitoring of predation on domestic animals by the Iberian lynx in the Sierra de Andújar, and explain the details of the prevention and compensation programme that aims to minimize the consequences of predation for local people, thereby preventing further lynx mortality due to illegal hunting.

Chapter 6) Provide an overview of the conservation tasks carried out to date and the situation of the Iberian lynx in the first decade of the twenty-first century.

To fulfil the aims of chapters 1 and 2, data from camera-traps were used to estimate lynx numbers via capture/recapture analysis. In Chapter 1, the camera-traps were set up over almost all of the species' distribution in Doñana, while in Chapter 2 simultaneous camera-trap sampling with and without attractant was conducted in a private estate in Andújar-Cardeña. In Chapter 3, a comparison was made between scat counts and camera-trapping using a simple regression analysis to test whether or not scat counts are able to forecast the lynx densities derived from the camera-trap data; in addition, the cost of both monitoring techniques was evaluated. Chapter 4 contains an estimate of the average annual mortality rates in lynx populations and their causes using data from 78 radio-tagged animals, while Chapter 5 consists of a compilation of all the information on lynx predation on domestic animals in the Andújar-Cardeña (Sierra Morena) area. Finally, Chapter 6 describes the efforts carried out over the past decade as part of various conservation programmes and their effects on Iberian lynx populations.

The results presented in Chapter 1 show that, as is the case in other felines, the application of capture/recapture analyses to data obtained by camera-trapping provides a reasonable estimate of lynx abundances. The estimate for the Doñana lynx population was around 26 (SE=5.26) lynxes over one year of age, which represented a significant decline in numbers since the 1980s and revealed changes in the spatial distribution of the species, thereby highlighting the species' critical situation in this area.

Chapter 2 discusses the fact that camera-trapping stations using attractant detect more individuals in less time and have a higher probability of photographing any given animal, which permits more exact population estimates to be reached. Thus, in conclusion, for the Iberian lynx the use of attractants with camera-traps increases the effectiveness, precision and efficiency of the abundance estimates calculated by capture/recapture analyses.

To date, the main way of monitoring lynx populations has been camera-trapping. However, as discussed in Chapter 3, scat counts are also reliable and inexpensive – above all, in comparison with the far more expensive use of camera-traps – ways of generating indices of spatial distribution and density in lynx populations. Given the expansion of Iberian lynx populations, the use of techniques such as camera-trapping may become both logistically and financially unfeasible. Scat censuses are thus a promising way of calculating lynx densities over large areas.

The actions undertaken by conservation projects to reduce Iberian lynx mortality were designed on the basis of existing mortality data, gathered above all in Doñana in the 1980s. Chapter 4 shows that disease is currently the main cause of death in the Iberian lynx population as a whole and is especially relevant in Doñana, possibly due to the immunosuppression resulting from the high levels of consanguinity that exist in this population. On the other hand, the principal cause of death in Sierra Morena is illegal hunting. The average annual mortality rates obtained in this study in both populations are lower than those from Doñana from 20 years ago, the only previous study of mortality in the species based on comparable data from radio-tracking techniques. The results suggest that the best strategy for the conservation of the species is to concentrate mitigating actions on diminishing the fatal effects of both disease and illegal hunting.

One of the actions undertaken to reduce illegal hunting is the setting up of a programme designed to compensate and prevent lynx attacks on domestic animals. The results of the monitoring of lynx predation events in the Andújar-Cardeña population over a period of six years (Chapter 5) indicate that the majority of these attacks are on domestic poultry (78%) and, to a lesser extent, on sheep. Nonetheless, the economic losses caused by attacks on sheep are greater. In cases of attacks on poultry, after compensation was paid and coops were remodelled, this conflict all but ceased to exist. Attacks on sheep, above all on extensively grazed flocks, caused much greater financial losses (720±360 € per attack on extensively grazed sheep flocks vs. 128.5±103.1 € per attack on poultry) and continue to occur. It is thus vital to test new prevention methods that will reduce the impact of lynx attacks on sheep in order to minimize conflicts with shepherds.

The on-going conservation and recovery plan for Iberian lynx populations developed over the past decade based on various individual conservation projects is described in Chapter 6. The main tasks contemplated by these projects, which aim to minimize the factors that threaten the species' survival, are as follows: 1) increase the carrying capacity of areas in which the lynx is present, principally by reinforcing wild rabbit populations; 2) reduce non-natural mortality rates; 3) set up a sanitary programme; 4) genetically reinforce the Doñana population; and 5) create new populations via reintroductions. The effectiveness of these actions was evaluated by monitoring both Iberian lynx (mostly using camera-traps) and rabbit populations. As a result of the conservation tasks carried out in 2002–210, the minimum number of lynxes detected by camera-traps rose from 93 to 252, and the species' area of occupation increased from 29,300 to 70,300 ha. As well, a programme was set up to genetically reinforce the Doñana population based on the translocation of four lynxes from the Sierra Morena, and two new populations in Sierra Morena were established by reintroduction. Nevertheless, the scenario facing the species is still uncertain. Any of the known threats could lead to the extinction of any one of the known populations. Its rarity and small number of populations, the loss of genetic viability, the risk of disease, non-natural mortality and viral disease in rabbits are all factors that still threaten the Iberian lynx. Its long-term survival requires the application of continuous efficient conservation measures, which implies a need for on-going schemes aimed at monitoring the evolution of lynx populations and the factors that negatively affect them. Given the number of negative factors that could affect the conservation of the species, the obtaining of reliable data must be a priority when designing and analysing monitoring programmes and future conservation actions.

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